Prepared for the
GEORGE C. MARSHALL
SPACE FLIGHT CENTER
Huntsville, Alabama

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IUS/TUG ORBITAL OPERATIONS and MISSION SUPPORT STUDY

FINAL REPORT

Vol. IV of V - Project Planning Data

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FOREWORD

This final report of the IUS/Tug Orbital Operations and Mission Study was prepared for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center by the IBM Corporation in accordance with Contract NAS8-31009.

The study effort described herein was conducted under the direction of NASA Contract Officer's Representative (COR), Mr. Sidney P. Saucier. This report was prepared by the IBM Corporation, Federal Systems Division, Huntsville, Alabama, under the direction of Mr. Roy E. Day, IBM Study Manager. Technical support was provided to IBM by the Philco-Ford Corporation, Western Development Laboratories Division, Palo Alto, California, under the direction of Dr. W. E. Waters, Philco-Ford Study Manager. The study results were developed during the period from June, 1974, through February, 1975, with the final report being distributed in May, 1975.

The results of this study have been documented in five separate volumes.

Volume I	Executive Summary
Volume II	IUS Operations
Volume III	Tug Operations
Volume IV	Project Planning Data
Volume V	Cost Estimates

Questions and comments regarding this study activity should be directed to:

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ACRONYMS AND ABBREVIATIONS

ACN -	Ascension Island, STDN Ground Station
ACS -	Attitude Control System
ADS -	Advanced Data System
AFSCF -	Air Force Satellite Control Facility
AFSTC -	Air Force Satellite Test Center
AGE -	Automated Ground Equipment
AGO -	Santiago, Chile - STDN Ground Station
AOS -	Acquisition of Signal
AZ-EL -	Azimuth - Elevation
BDA -	Bermuda (U.K) - STDN Ground Station
B/U -	Backup
C&D -	Control and Display
C&W -	Caution and Warning
CCTV -	Closed Circuit Television
CMDS -	Command
C/O -	Checkout
CYI -	Canary Island - STDN Ground Station
DFCS -	Digital Flight Control System
DMS -	Data Management System
DoD -	Department of Defense
DSN -	Deep Space Network
EIUS -	Expendable Interim Upper Stage
EVA -	Extravehicular Activity
FPS -	Feet Per Second
GDS -	Goldstone, Calif. - STDN Ground Station
GMT -	Greenwich Mean Time
GN&C -	Guidance, Navigation and Control
GND -	Ground
GPCF -	General Purpose Control Facility
GSE -	Ground Support Equipment
GSFC -	Goddard Space Flight Center, Greenbelt, MD.
GWM -	Guam Island - STDN Ground Station
HAW -	Hawaii - STDN Ground Station
HSK -	Honeysuckle Creek (Canberra), Australia - STDN Ground Station
IGPS -	Inertial Guidance Power System
IGS -	Inertial Guidance System
IMU -	Inertial Measuring Unit
IUS -	Interim Upper Stage
IUS/OC -	Interim Upper Stage Operations Center

ACRONYMS AND ABBREVIATIONS (Continued)

JPL - Jet Propulsion Lab, Pasadena, California
JSC - Johnson Spacecraft Center, Houston, Texas

KADS - Kilo-Add Instruction Executions Per Second
KBPS - Kilobits Per Second
KM - Kilometers
KOPS - Kilo-Operations Per Second
KS - Kick Stage
KSA - Ku-Band Single-Access
KSC - Kennedy Space Center, Cape Canaveral, Florida

LOS - Loss of Signal/Line of Sight
LPS - Launch Processing System

MA - Multiple Access
MAD - Madrid, Spain - STDN Ground Station
M&O - Maintenance and Operations
MBPS - Megabits Per Second
MCC - Mission Control Center
MDM - Multiplexer/Demultiplexer (Orbiter)
MGC - Missile Guidance Computer (IUS)
MHz - Megahertz
MIL - Merritt Island, Florida - STDN Ground Station
MPS - Main Propulsion System
MSFC - Marshall Space Flight Center, Huntsville, Alabama
MSS - Mission Specialist Station (Orbiter)

NASA - National Aeronautics and Space Administration
NASCOM - NASA Communications Network
NOCC - Networks Operations Control Center

ODS - Orbit Determination System
ORR - Orroral, Australia - STDN Ground Station
OS - Operating System (Software)

PCM - Pulse Code Modulation
PDI - Payload Data Interleaver (Orbiter)
PMOCC - Pioneer Mission Operations Control Center
PMS - Performance Monitoring System
PN - Pseudonoise
POCC - Project Operations Control Center
PSP - Payload Signal Processor (Orbiter)
PSS - Payload Specialist Station (Orbiter)
PU - Propellant Utilization

QUI - Quito, Equador - STDN Ground Station

ACRONYMS AND ABBREVIATIONS (Continued)

RCS -	Reaction Control System (Orbiter)
RF -	Radio Frequency
RFI -	Radio Frequency Interference
RIUS -	Reusable Interim Upper Stage
RMIS -	Remote Multiplexer Instrumentation System (IUS)
RMS -	Remote Manipulator System (Orbiter)
RMU -	Remote Multiplexer Unit (IUS)
ROS -	Rosman, N.C. - STDN Ground Station
R&RR -	Range and Range Rate
RTCC -	Real Time Computer Complex
RTS -	Remote Tracking Station
SA -	Single Access
S/C -	Spacecraft
SCF -	Satellite Control Facility
SGLS -	Space Ground Link System
SIRD -	Support Instrumentation Requirements Document
SOC -	Spacecraft Operations Center
SPO -	Space Project Office
SSA -	S-Band Single Access
STDN -	Spaceflight Tracking and Data Network
TAN -	Tananarive, Malagasy Republic - STDN Ground Station
TBD -	To Be Determined
TDRS -	Tracking and Data Relay Satellite
TDRSS -	Tracking and Data Relay Satellite System
TM -	Telemetry
TOC -	Tug Operations Center
TTY -	Teletype
ULA -	Fairbanks, Alaska - STDN Ground Station
Vdc -	Direct Current Voltage
ZOE -	Zones of Exclusion
ΔV -	Delta Velocity

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INTRODUCTION 1

1.0 PURPOSE

The purpose of this document is to present the planning data for the subsequent development phases of the IUS and Tug systems defined in Volumes II and III of this report. Included in the document are the major project planning requirements, major event schedules, milestones, and system development and operations process networks, and relevant support research and technology requirements.

Fundamental to the success and efficiency of any complex system development and operations effort is the quality of the plan for accomplishment and the continual maintenance by management of that plan. The identification and sequencing of the major tasks required for the development of an IUS/Tug Operational System is an essential step toward this goal. The tasks included in this project planning data document provide planners a preview of the type, size, sequence, and criticality of the essential efforts necessary to achieve an economical IUS/Tug system in the desired time frame. The method utilized to present this information is a flexible tool which readily permits the necessary changes with the refinement of IUS/Tug system descriptions. We believe that the planning data in this document is currently relevant and presented in a manner which should facilitate utilization.

2.0 SCOPE

The project planning data contained in this report is limited to the following major IUS/Tug system elements:

- IUS Flight Software
- Tug Flight Software
- IUS/Tug Ground Control Center Facilities
- IUS/Tug Ground Control Center Personnel
- IUS/Tug Ground Control Center Data System
- IUS/Tug Ground Control Center Software
- IUS/TUG Ground Control Center Equipment
- IUS Mission Events
- Tug Mission Events
- Tug/Spacecraft Rendezvous and Docking
- Tug/Orbiter Operations Interface
- IUS/Orbiter Operations Interface

Because the system elements listed do not represent the total IUS/Tug system, the project planning data presented in this document should be considered only applicable to those elements included in the study. The techniques used to display this information are, however, equally applicable to those other major areas, such as vehicle hardware, testing, prelaunch assembly and checkout. These additional areas could be added to the present data to complete the total IUS/Tug system project planning data.

PART A

PROJECT PLANNING REQUIREMENTS

1.0 GENERAL

The purpose of this section of the document is to identify the gross project planning requirements with respect to the normal areas of responsibility associated with a space systems development effort. The specific areas to be defined are as follows:

Engineering and Manufacturing
Testing
Quality and Reliability Assurance
Facilities
Project Management
Logistics
Operations
Program Risks

Project planning requirements for each of these areas will be presented in the order of planned occurrence in bar chart form. This will permit easy recognition of the concentration of task associated effort of each area and give a sequential and overlap picture of the tasks in which each area is involved. Verbal explanations of each task appearing on the charts are presented in Volume III, Section 10 of this study.

2.0 SPECIFIC AREA PLANNING REQUIREMENTS

2.1 ENGINEERING AND MANUFACTURING

The Engineering and Manufacturing area of responsibility addresses those efforts relating to system definition, design, build, installation and real time mission operations support activities. Figure A-1 illustrates in bar chart form, the major tasks involving Engineering and Manufacturing.

It is immediately obvious from Figure A-1 that the engineering involvement in the IUS/Tug operations system is continuous from inception (the first quarter of 1977) to development completion (the fourth quarter of 1983). This is not surprising, considering the complex nature of the operations system and the equally complex and versatile mission it is to perform. Individual tasks in the unbroken sequence can not be singled out as being the key to successful system development. The key to success is in the planning and accomplishment of the tasks in a timely manner so that other areas of development are not impacted by this, the most important and involved area of planning requirements responsibility.

2.2 TESTING

The testing area of responsibility relates to those activities involved in test and checkout of the hardware, delivered software and integrated systems. Figure A-2 illustrates in bar chart form, the major tasks involving testing area participation. Major testing efforts include IUS and Tug flight software, IUS and Tug network compatibility and the verification of the total integrated IUS and Tug operational system.

2.3 QUALITY AND RELIABILITY ASSURANCE

The Quality and Reliability Assurance area includes those efforts relating to the assignment and verification of hardware, software, and integrated system reliability numbers and the inspection and quality control efforts associated with product assurance. Figure A-3 shows by sequential bar chart the tasks which will involve quality and reliability assurance participation.

As may be seen from the information presented in Figure A-3, the greatest involvement of quality and reliability assurance is associated with the IUS and Tug flight software which relates directly to crew safety and mission success probability.

2.4 FACILITIES

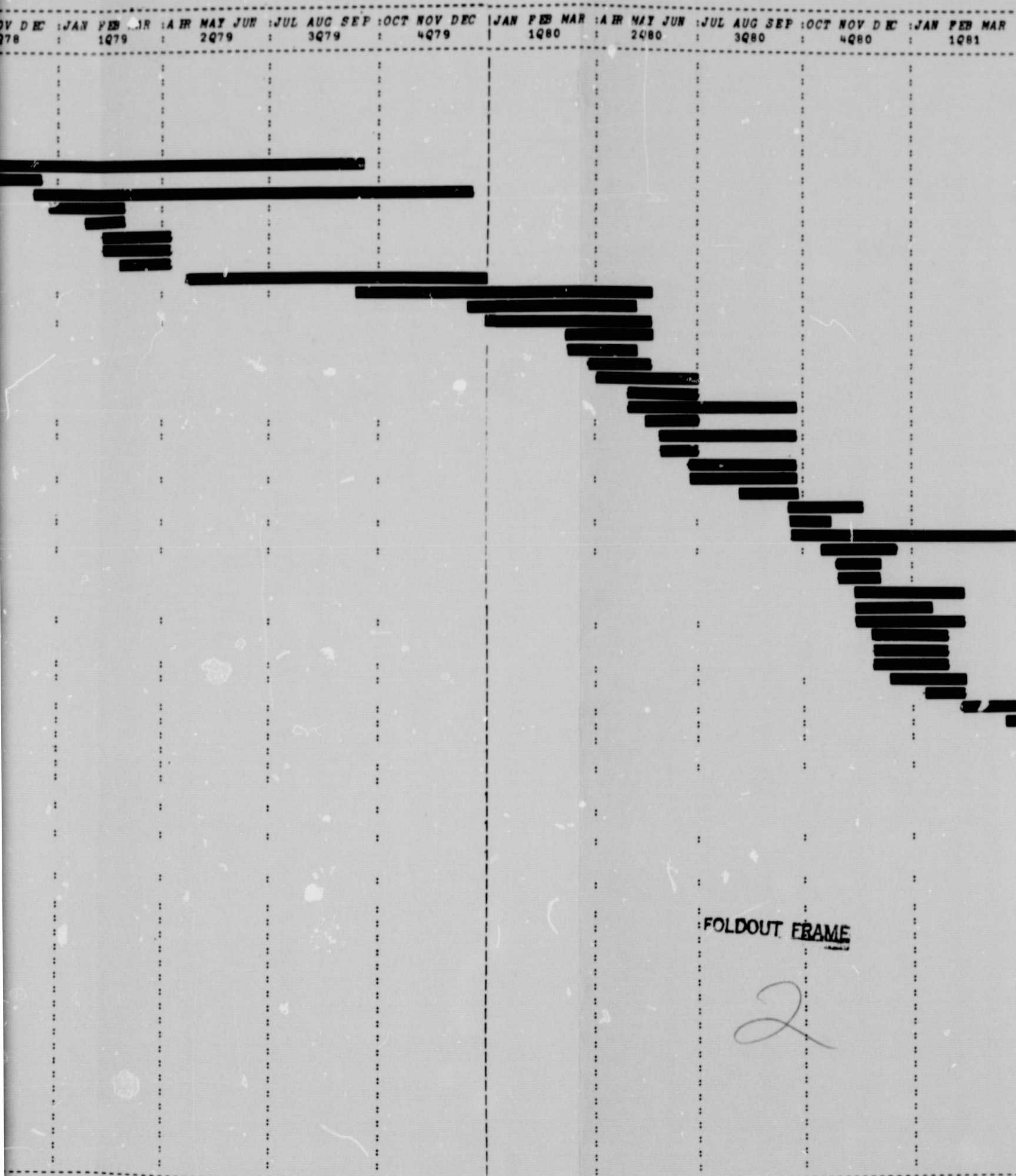
The Facilities area of responsibility pertains to those tasks related to the physical construction of the IUS/Tug ground control center and the installation of the flight operations support equipment. Figure A-4 shows the scheduled start and completion dates for these activites. At present, only three major elements of responsibility are included in the planning data involving the Facilities area. They are physical plant construction, installation of the operational data systems, and installation of the flight operations equipment peculiar to a real time flight control center. The scheduling of these tasks are consistent with premission utilization activities such as integrated systems test and flight control simulation and training.

2.5 PROJECT MANAGEMENT

The Project Management Area (Figure A-5) includes those tasks which would involve directly project management. This does not mean that project management would not be responsible for the management of the total development effort or would not be interested in a management capacity in the other tasks.

Tasks involving project management encompass those efforts which produce, maintain and monitor the overall IUS/Tug operations system development plan. Also included are those tasks which coordinate and exchange information with other Space Transportation System programs. Concentrations of effort have been identified in the fourth quarter of 1980, first quarter of 1981, and third quarter of 1983.

Figure A-1. Engineering and Manufacturing Planning Requirements



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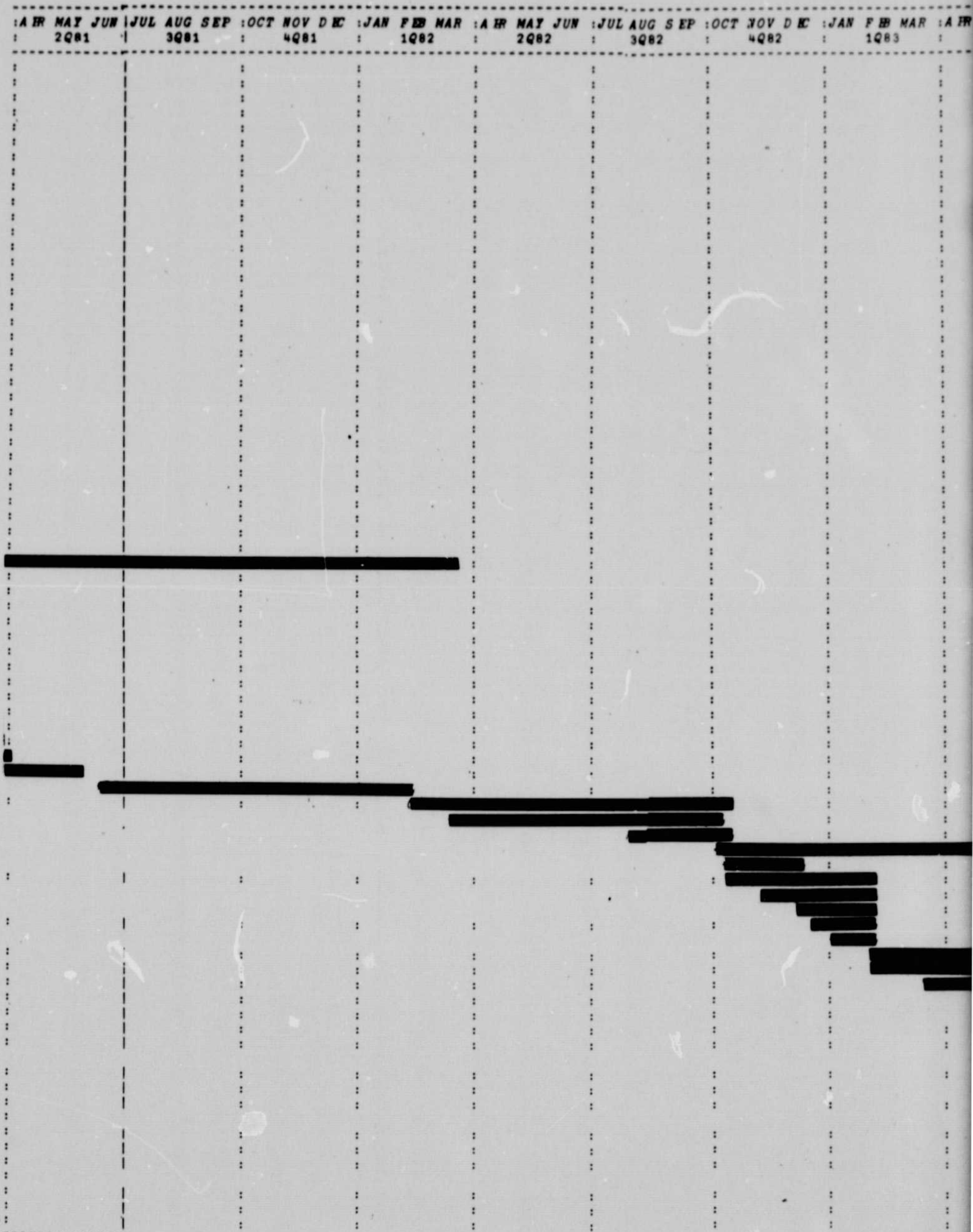

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:JAN FEB MAR :APR MAY JUN :JUL AUG SEP :OCT NOV DEC |           |
:    1Q83    :    2Q83    :    3Q83    :    4Q83    |DESCRIPTION|
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|PLAN GROUND SOFTWARE DEVELOPMENT
|EDD-EXECUTIVE/TRACKING/PLANNING
|EDD-TUG DOWNDATA/UPDATA/DOCKING/SI
|EDD-IUS DOWNDATA/UPDATA/SIMULATION
|MASTER LAUNCH SCHEDULE ANALYSIS
|TUG MISSION CHARACTERIZATION
|IUS MISSION CHARACTERIZATION
|PROGRAM GROUND TK/PLAN/EX SOFTWARE
|PLAN FLIGHT SOFTWARE DEVELOPMENT
|EDD-IUS FLIGHT PROGRAM
|COMPUTER UTILIZATION PLAN
|ESTIMATE GROUND SOFTWARE SIZE
|TUG DISPLAY FORMAT DESIGN
|IUS DISPLAY FORMAT DESIGN
|SELECT OPERATIONAL DATA SYSTEM
|PROGRAM IUS DNDATA/UPDATA/SIMULATI
|VERIFY EXECUTIVE/TK/PLAN SOFTWARE
|PROGRAM IUS FLIGHT SOFTWARE
|VERIFY IUS DNDATA/UPDATA/SIM PROGR
|COMMON GND SW VALID TEST REQUIREME
|DETERMINE IUS FAILURE MODES
|IUS GND SW VALID TEST REQUIREMENTS
|CONSOLE POSITION GUIDELINES
|IUS MISSION FAILURE EFFECTS
|IUS FLT PROGRAM VERIFICATION
|IUS MISSION PLANNING AND OPTIMIZAT
|DEVELOP IUS PROCEDURES AND RULES
|DEFINE IUS OPERATOR CERT/CRITERIA
|DESIGN IUS MISSION SIMULATION
|IUS ABORT PLANNING
|ANALYZE IUS COMPONENT CHARACTERIST
|PREPARE IUS SYSTEMS HANDBOOK
|IUS MISSION SPEC EDD
|EDD-TUG FLIGHT PROGRAM
|IUS MISSION SPEC PROGRAM
|DEFINE NETWORK TRACKING REQUIREMEN
|IUS NETWORK DATA HANDLING REQUIREM
|PUBLISH/UPDATE IUS HANDBOOK
|DEVELOP IUS TRAINING MATERIAL
|PROGRAM IUS MISSION SIMULATION
|NETWORK TRACKING VALID PROCEDURES
|IUS NETWORK DATA VALID PROCEDURES
|PREPARE IUS INTERAGENCY DOCUMENTS
|IUS MISSION PROGRAM VERIFICATION
|IUS CLASSROOM TRAINING
|IUS MISSION SIMULATION TRAINING
|CONDUCT IUS MISSION OPERATIONS
|IUS POST MISSION REPORTS
|PROGRAM TUG DNDATA/UPDATA/DOCKING/
|VERIFY TUG DNDATA/UPDATA/DOCKING/S
|PROGRAM TUG FLIGHT SOFTWARE
|TUG GND SW VALID TEST REQUIREMENTS
|TUG FLT PROGRAM VERIFICATION
|DETERMINE TUG FAILURE MODES
|DEVELOP TUG PROCEDURES AND RULES
|TUG CONSOLE POSITION GUIDELINES
|TUG MISSION FAILURE EFFECTS
|TUG MISSION PLANNING AND OPTIMIZAT
|DEFINE TUG OPERATOR CERT/CRITERIA
|DESIGN TUG MISSION SIMULATION
|TUG ABORT PLANNING
|ANALYZE TUG COMPONENT CHARACTERIST
|TUG TRAINING REQ/CRIT/SIMSKED
|PREPARE TUG SYSTEMS HANDBOOK
|TUG MISSION SPEC EDD
|TUG MISSION SPECIFIC PROGRAM
|TUG NETWORK DATA HANDLING REQUIREM
|PUBLISH/UPDATE TUG SYSTEMS HANDBOO
|DEVELOP TUG TRAINING MATERIAL
|PROGRAM TUG MISSION SIMULATION
|TUG NETWORK DATA VALID PROCEEDURES
|PREPARE TUG INTERAGENCY DOCUMENTS
|TUG MISSION PROGRAM VERIFICATION
|TUG CLASSROOM TRAINING
|TUG NETWORK VALID TESTS
|TUG MISSION SIMULATION TRAINING
|CONDUCT TUG MISSION OPERATIONS
|TUG POST MISSION REPORTS

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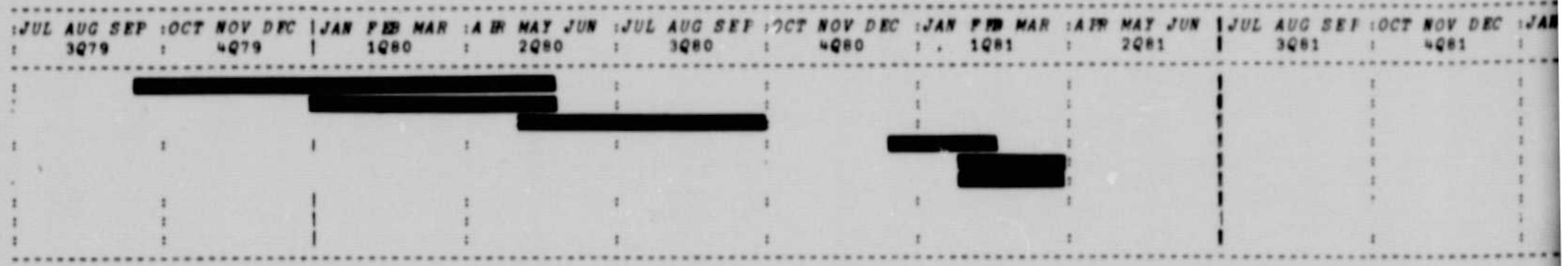

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Figure A-2. Testing Planning Requirements

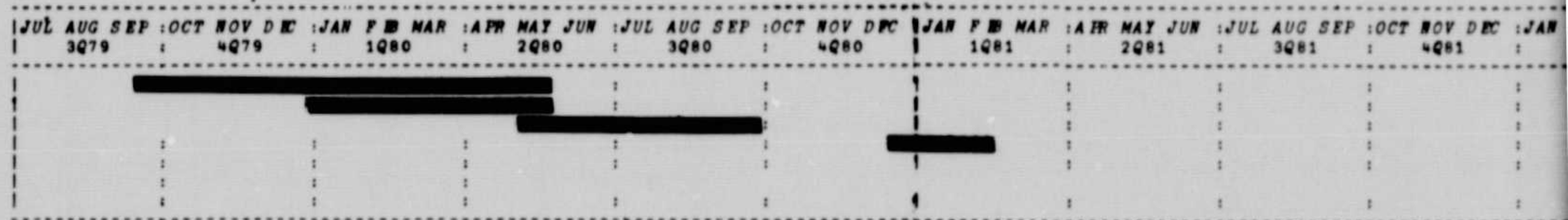

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Figure A-3. Quality and Reliability Assurance Planning Requirements

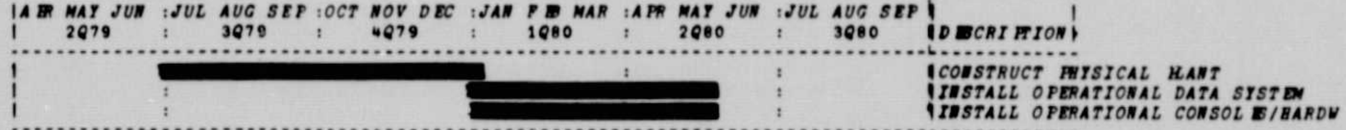

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Figure A-4. Facility Planning Requirements

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									VERIFY EXECUTIVE/TK/PLAN SOFTWARE
									VERIFY IUS DNDATA/UPDATA/SIM PROGR
									IUS FLT PROGRAM VERIFICATION
									IUS MISSION PROGRAM VERIFICATION
									NETWORK TRACKING VALID TESTS
									IUS NETWORK DATA VALID TESTS
									VERIFY TUG DNDATA/UPDATA/DOCKING/S
									TUG FLT PROGRAM VERIFICATION
									TUG MISSION PROGRAM VERIFICATION

G SEP 81	OCT NOV DEC 4Q81	JAN FEB MAR 1Q82	APR MAY JUN 2Q82	JUL AUG SEP 3Q82	OCT NOV DEC 4Q82	JAN FEB MAR 1Q83	APR MAY JUN 2Q83	JUL AUG SEP 3Q83	DESCRIPTION
									VERIFY EXECUTIVE/TK/PLAN SOFTWARE
									VERIFY IUS DNDATA/UPDATA/SIM PROGR
									IUS FLT PROGRAM VERIFICATION
									IUS MISSION PROGRAM VERIFICATION
									VERIFY TUG DNDATA/UPDATA/DOCKING/S
									TUG FLT PROGRAM VERIFICATION
									TUG MISSION PROGRAM VERIFICATION

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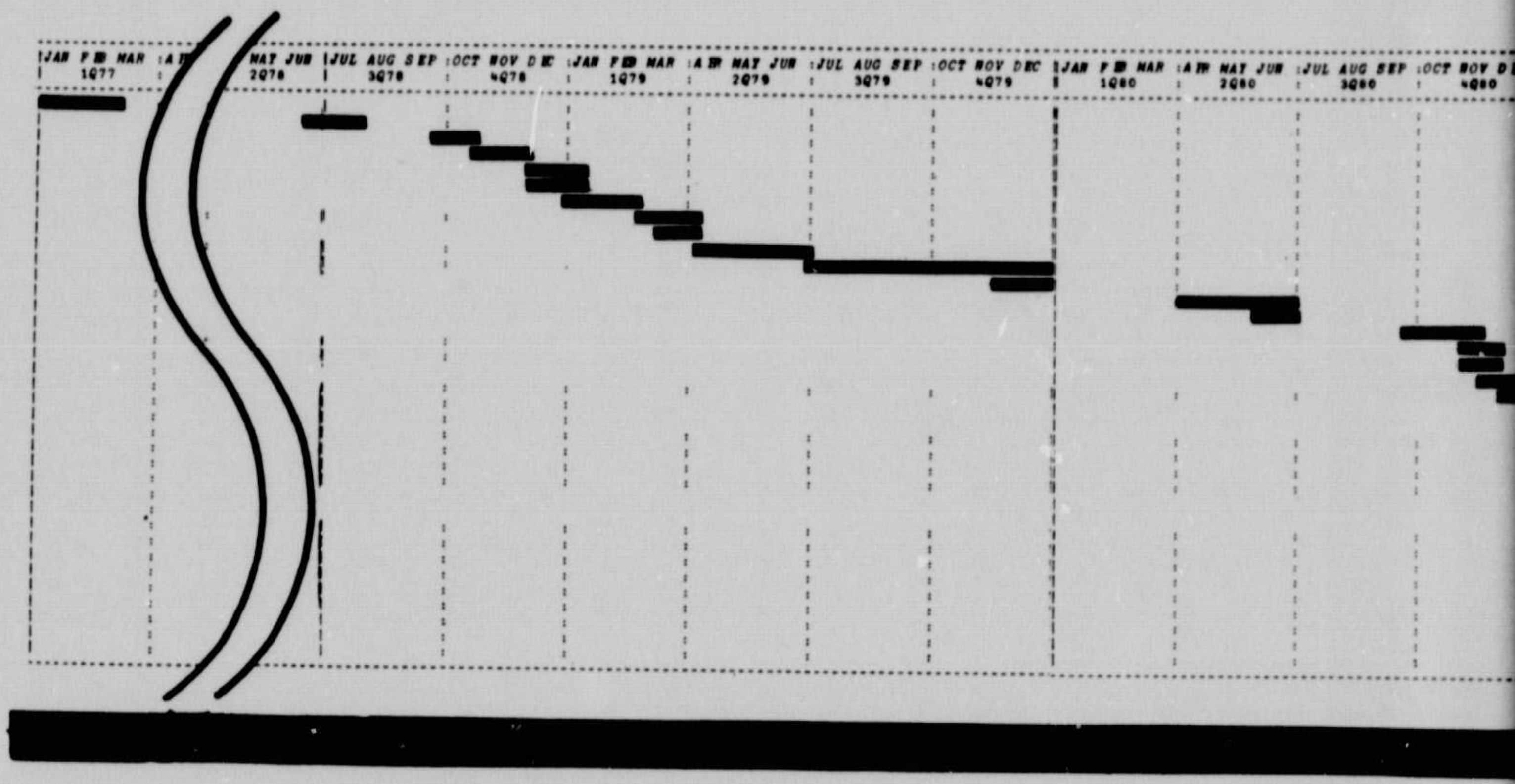

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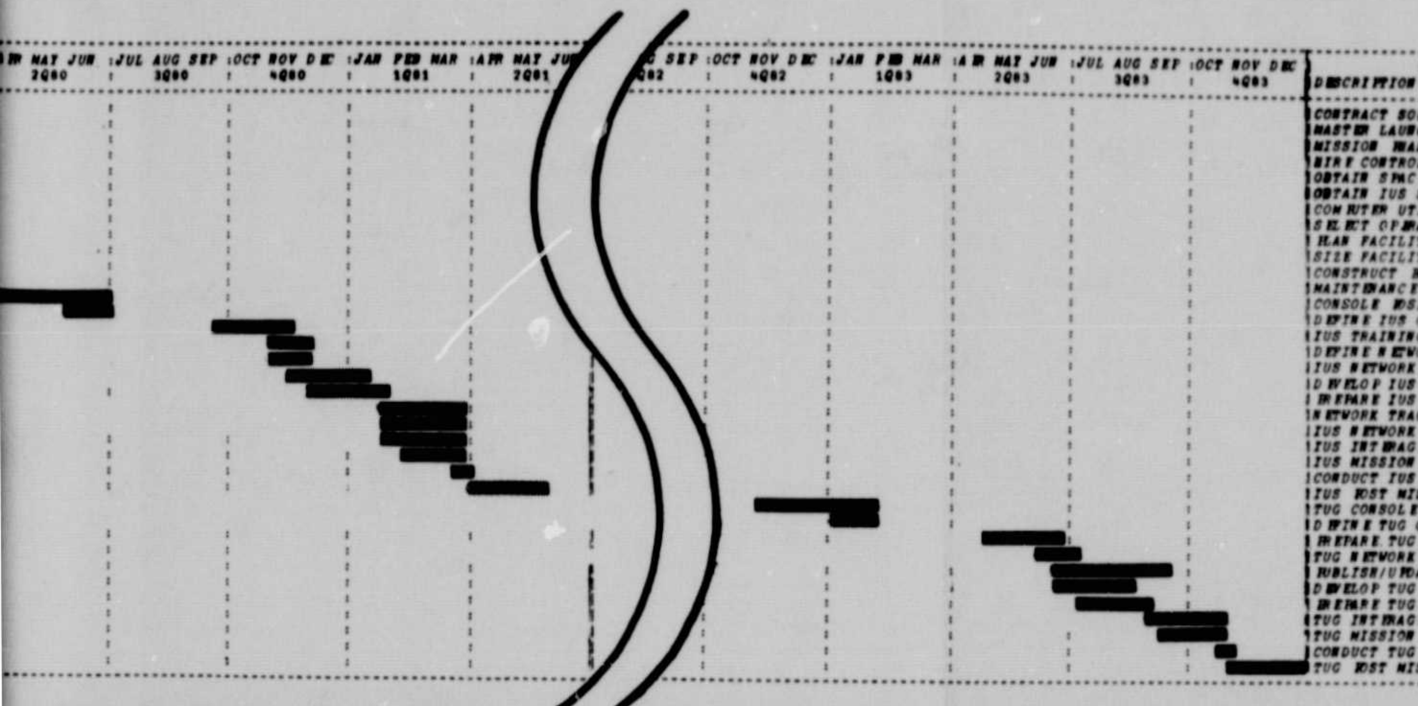

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Figure A-5. Project Management Planning Requirements

2.6 LOGISTICS

The Logistics Area pertains to those tasks involving support efforts required for the development and operation of the IUS/Tug system. Figure A-6 illustrates in bar chart form those major tasks included in the Logistics area.

During the development effort, direct logistics support will be in the scheduling, ordering, and securing materials and training personnel in a timely manner to insure elements critical to the overall IUS/Tug systems development effort are available when needed. Major quarters of activity are the fourth quarter of 1980 and second and third quarters of 1983.

2.7 OPERATIONS

The Operations area involves the tasks associated with preparing for and operating the IUS/Tug operations system. Figure A-7 is a bar chart which illustrates those major tasks which must include the involvement of the operations area.

Like engineering, the operations area is involved almost continuously from the second quarter of 1977 till the fourth quarter of 1983. Since the purpose of the IUS/Tug operations system is to serve a complex, multi-purposed spacecraft delivery, retrieval, and service system it is not surprising that the influence of operations must be imposed at each development step. The significant aspect of this chart is to emphasize that operational effect must be continually factored into the IUS/Tug operations system development process.

2.8 PROGRAM RISKS

The Program Risks area pertains to those tasks which are extremely critical to the total effort and/or require technology which must be developed. Tasks of uncertain cost could also be considered critical.

Under this criteria no task among those listed could be singled out as qualifying as a program risk. However, the sequencing and scheduling of tasks included in critical paths as shown in Figure B-3 of this document could formulate a problem and program liability if allowed to slip. From this analysis it can be concluded that the greatest risk to a program of this magnitude and complexity is not having and following a planned method of producing the total operations system on schedule. The sequencing and sizing of tasks as shown in this document represent an initial step in the development of such a plan.

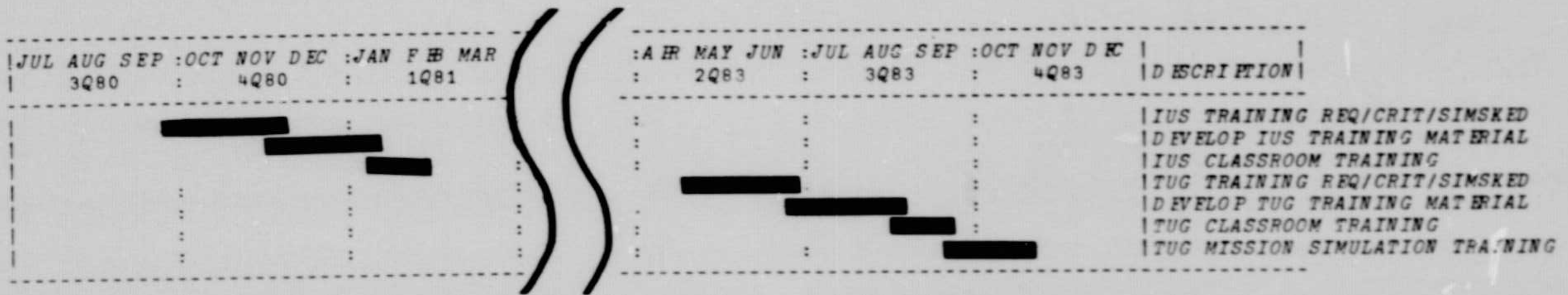

Figure A-6. Logistics Planning Requirements

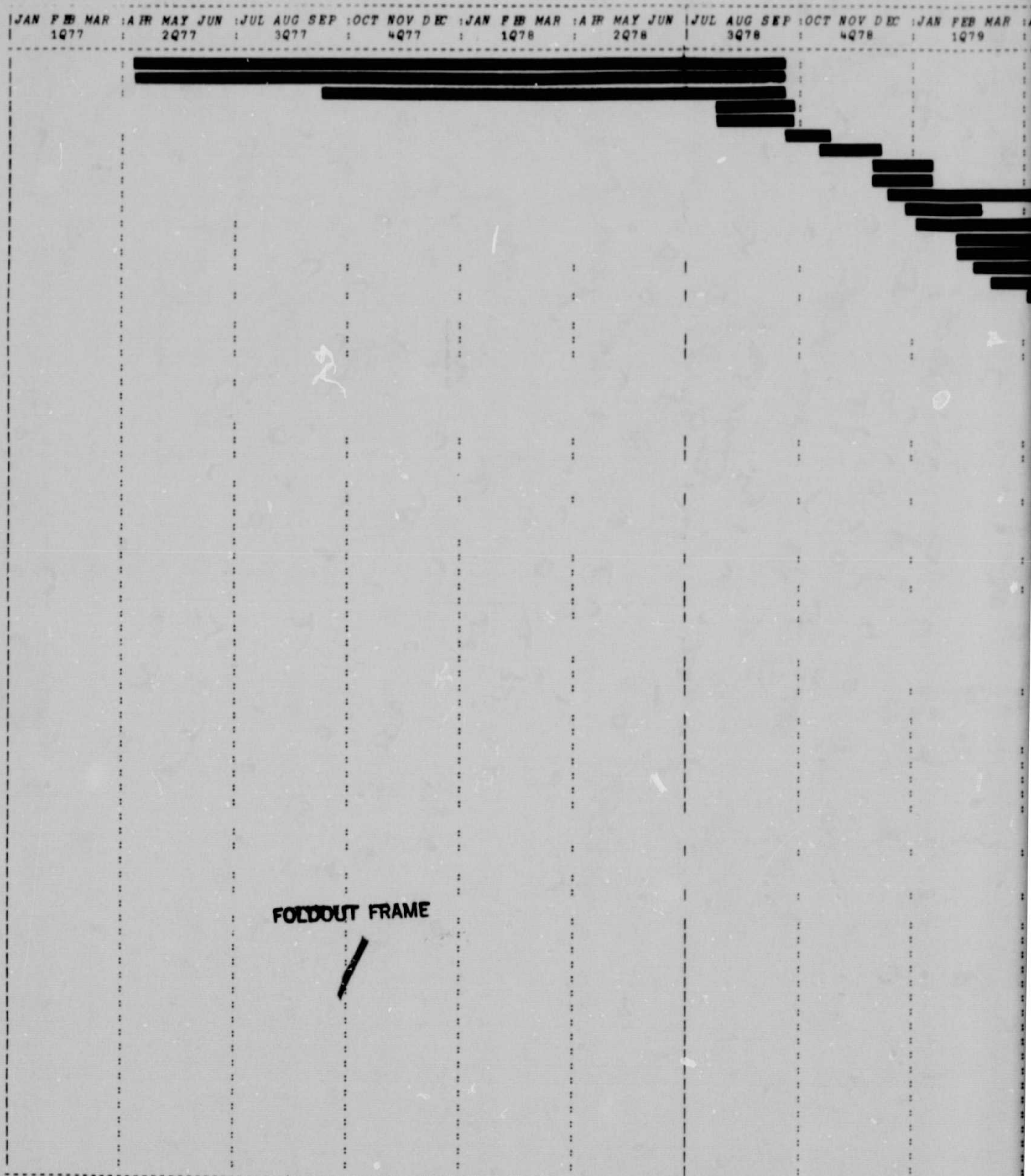

Figure A-7. Operations Planning Requirements

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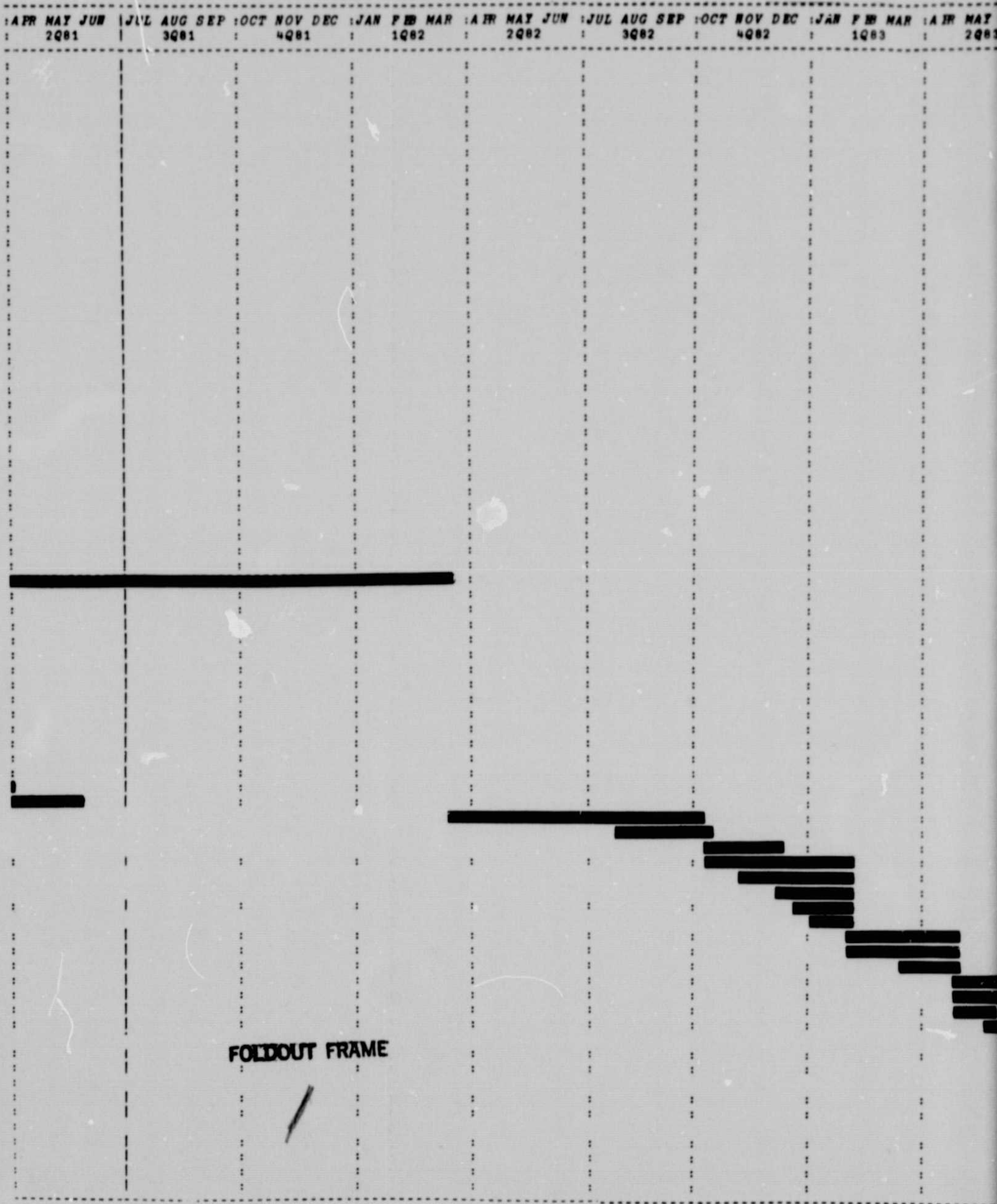

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JAN FEB MAR 1Q83	APR MAY JUN 2Q83	JUL AUG SEP 3Q83	OCT NOV DEC 4Q83	DESCRIPTION
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				EDD-TUG DOWNDATA/UPDATA/DOCKING/SI
				EDD-IUS DOWNDATA/UPDATA/SIMULATION
				TUG MISSION CHARACTERIZATION
				IUS MISSION CHARACTERIZATION
				MISSION PHASE MANNING REQUIREMENTS
				HIRE CONTROL ANS SUPPORT STAFF
				OBTAIN SPACE TUG SYSTEM CHARACTERI
				OBTAIN IUS SYSTEM CHARACTERISTICS
				EDD+IUS FLIGHT PROGRAM
				COMPUTER UTILIZATION PLAN
				DESIGN NETWORK INTERFACE SYSTEM
				TUG DISPLAY FORMAT DESIGN
				IUS DISPLAY FORMAT DESIGN
				SELECT OPERATIONAL DATA SYSTEM
				CONSOLE ORGANIZATION
				SIZE FACILITY/DESIGN PHYSICAL PLAN
				MAINTENANCE SCHEDULE
				PROGRAM IUS FLIGHT SOFTWARE
				INSTALL OPERATIONAL DATA SYSTEM
				INSTALL OPERATIONAL CONSOLES/HARDW
				COMMON GND SW VALID TEST REQUIREME
				DETERMINE IUS FAILURE MODES
				IUS GND SW VALID TEST REQUIREMENTS
				CONSOLE POSITION GUIDELINES
				IUS MISSION FAILURE EFFECTS
				IUS MISSION PLANNING AND OPTIMIZAT
				DEVELOP IUS PROCEDURES AND RULES
				DEFINE IUS OPERATOR CERT/CRITERIA
				DESIGN IUS MISSION SIMULATION
				IUS ABORT PLANNING
				ANALYZE IUS COMPONENT CHARACTERIST
				IUS TRAINING REQ/CRIT/SIMSKED
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				NETWORK TRACKING VALID PROCEDURES
				IUS NETWORK DATA VALID PROCEDURES
				PREPARE IUS INTERAGENCY DOCUMENTS
				IUS CLASSROOM TRAINING
				NETWORK TRACKING VALID TESTS
				IUS NETWORK DATA VALID TESTS
				IUS INTERAGENCY COORDINATION
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				TUG INTERAGENCY COORDINATION
				TUG MISSION SIMULATION TRAINING
				CONDUCT TUG MISSION OPERATIONS
				TUG POST MISSION REPORTS

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PART B

NETWORKS, SCHEDULES AND MILESTONES

1.0 GENERAL

This section contains the networks, schedules and milestones necessary to show the predecessor and successor events and activities directly related to the development and initial operation of the overall IUS/Tug operations system. The planning data included in these charts are consistent with the IUS to Tug transistional development plan presented in Volume III of this study and the costing information presented in Volume V. Major emphasis is placed on the system development task sequence and schedules covering the period between the first quarter of 1977 through the fourth quarter of 1982. An initial IUS single mission preparation and operations effort is also included to illustrate the development tasks associated with an initial flight operation.

2.0 NETWORKS

2.1 IUS/TUG SYSTEMS DEVELOPMENT PROCESS

The most cost-effective approach to the overall space transportation system problem in the upper stage area is to maximize the utilization of operational support elements which are common between the IUS and the Space Tug program. The key to maximizing this utilization is in the detail, adequacy and flexibility of the initial planning effort.

In order to do this, a PERT chart was constructed containing the tasks required for the development of the IUS and Tug operations system, and analysis on that flow was iterated until a comprehensive development plan was established for both the IUS and the Space Tug programs. Figure B-1 presents the PERT chart for the composite program development process.

This chart was generated by the IBM mini-PERT program which was designed for APL terminal usage, and, therefore, is not in the form most frequently seen. Briefly, the chart consists of a series of event designators displayed across the top of the chart, and strings of activities which span the space between event designators. An event designator is equivalent to a "bubble" on the more frequently seen PERT chart. The significance of the event designator is that it represents a point in the activity flow of a program which must be reached prior to beginning subsequenct activities dependent on its completion.

Just below the event designators are two dates associated with each event, an early date and a late date. These dates are considered to be either starting dates or finishing dates depending upon whether the consideration is the activities which begin at the event, or activities which end at the event. The early and late dates of the event correspond with the early and late dates of the associated activities. For example, the earliest that activities subsequent to event 26 can begin is April 11, 1977, which is the earliest that all constraints can be met and September 18, 1978, is the latest that pre-

decessor activities can begin without impacting the overall schedule. The activity is bounded on each end by an event, and the time space between the event is determined by the effort that must be applied during the activity. An activity is time consuming and resource consuming. Progression of activities is from left to right across the chart with vertical extensions to pick up parallel paths.

2.2 IUS INITIAL SYSTEMS OPERATIONS PROCESS

Figure B-2 presents in bar chart form the recurring tasks expected for initial IUS missions. The numbers in the bars represent the expected manpower required for each task the first time it is performed. It is reasonable to assume that as mission experience increases, manpower and time requirements for these tasks will be reduced. The time period displayed covers a fifty-three week period. Details concerning this effort can be found in the transition analysis section of Volume III.

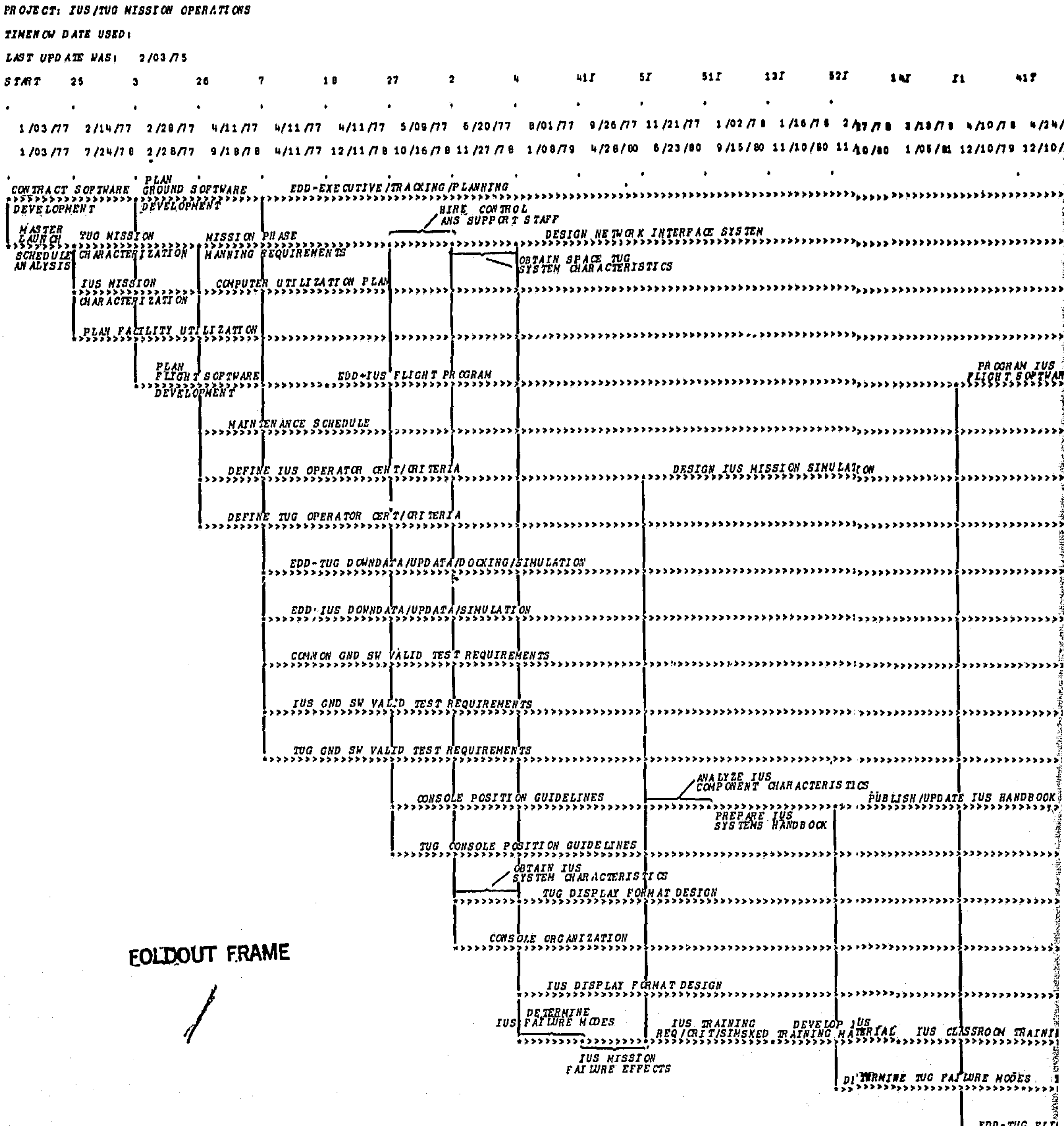

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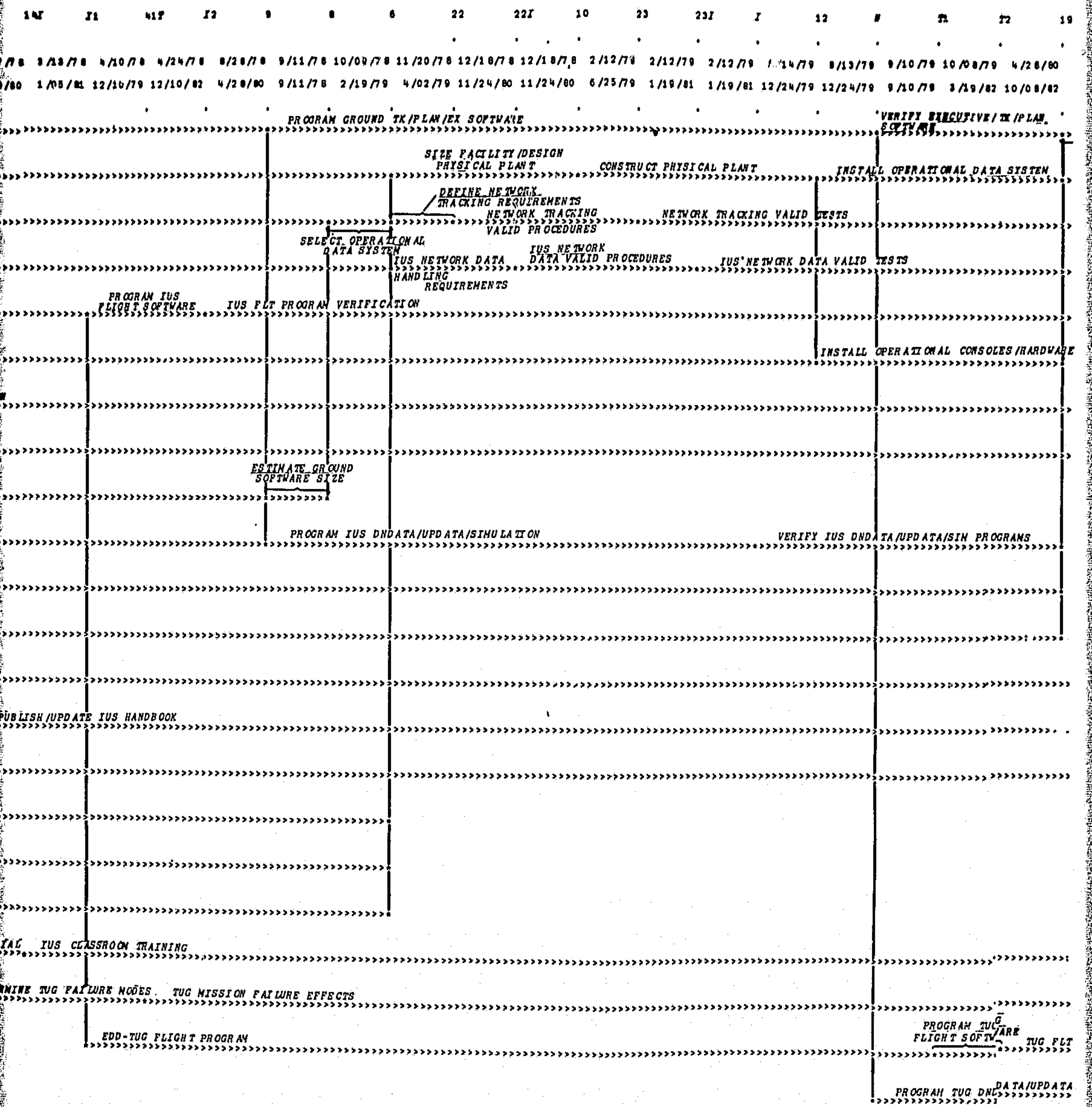
Figure B-1. IUS/Tug Systems Development Process



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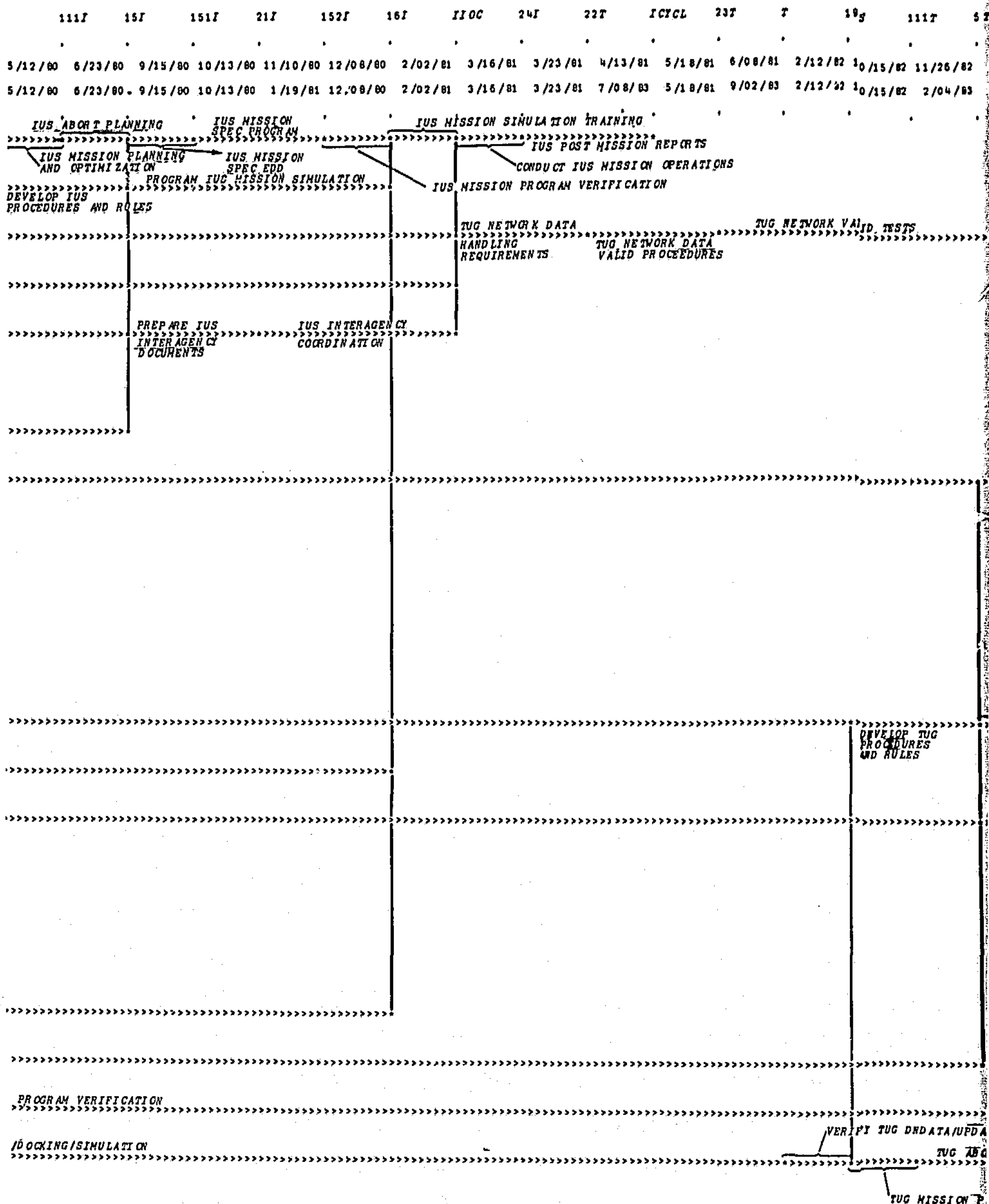

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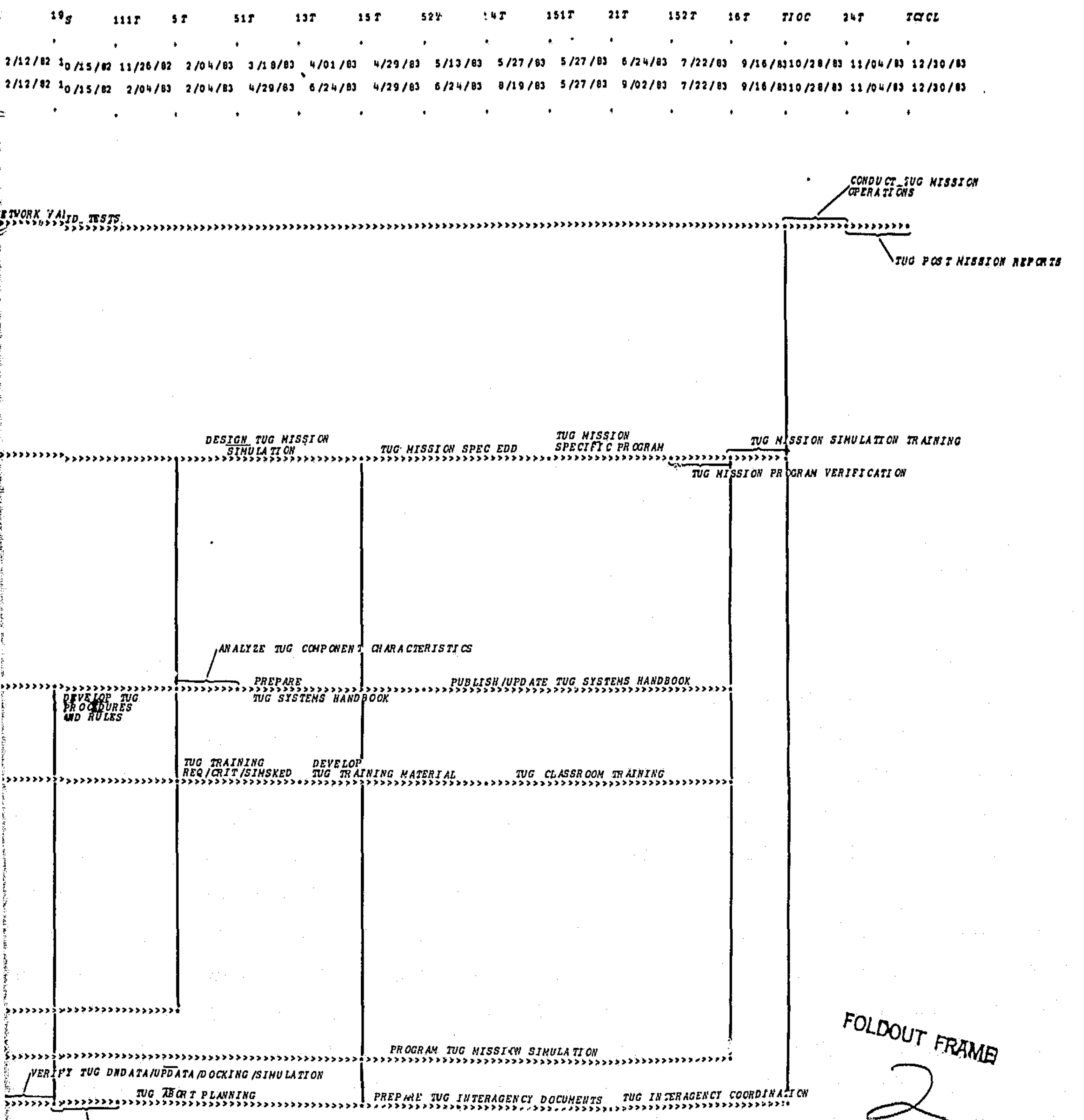

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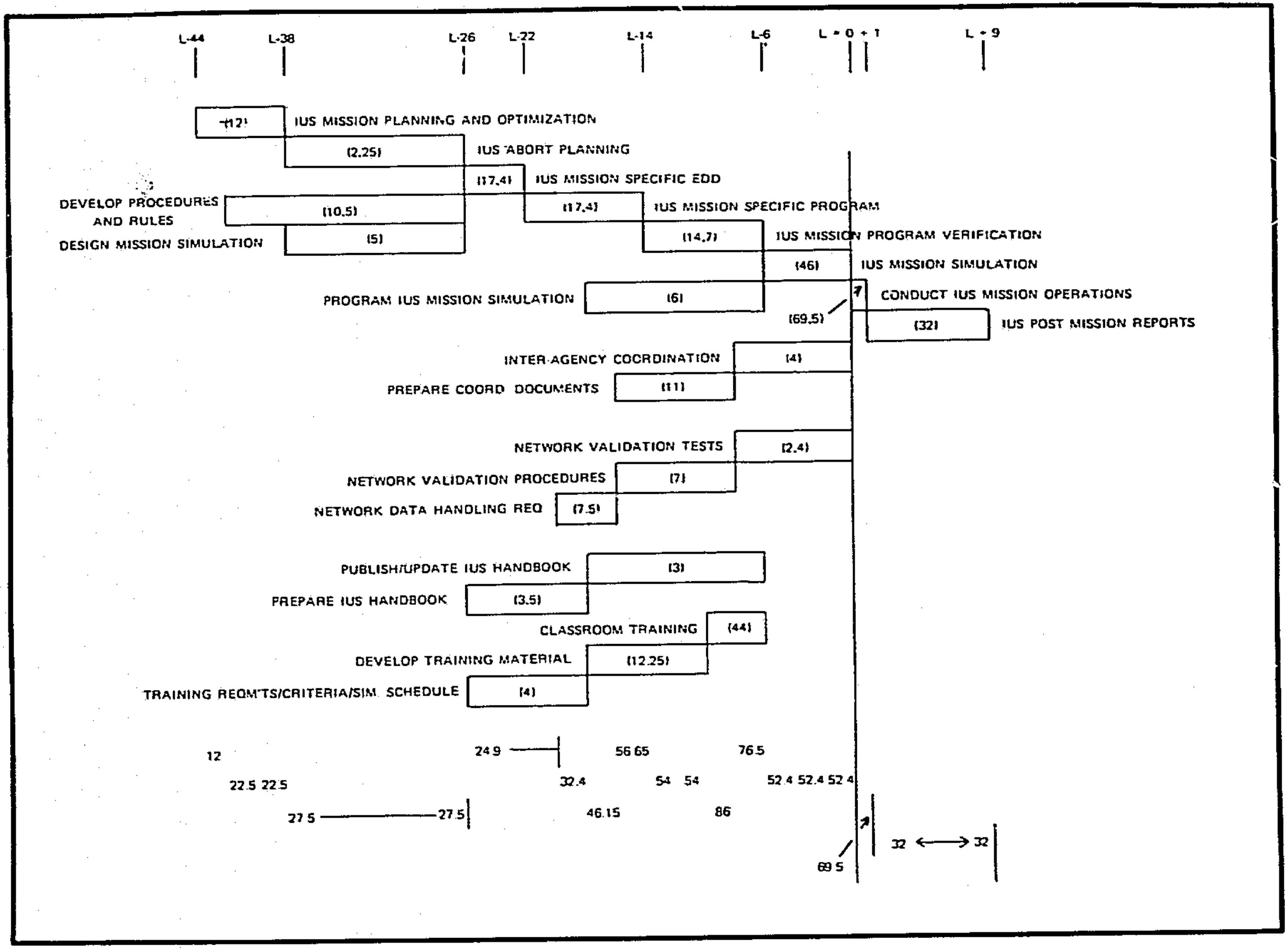

Figure B-2. IUS Initial Systems Operations Process

3.0 SCHEDULES

3.1 IUS/TUG SYSTEMS DEVELOPMENT SCHEDULE

A bar chart schedule of the overall development tasks required are presented in Figure B-3. The bar chart is segregated into calendar quarters spanning the time from first quarter 1977 through fourth quarter 1983. The chart was derived from the PERT Network shown in Figure B-1.

There exists a path which constrains the earliest date the project can be finished as a function of the established date that the project must start. This path is called the "critical path", and all activities in the program will fit within the constraints of the beginning and ending of the critical path. In generating the PERT chart, the critical paths for the IUS and Space Tug program were created by postulating a first mission for the IUS in April, 1981, and a first mission for the Space Tug in November, 1983. These postulates establish the latest possible start time for (IUS and common) elements in the first quarter of 1977. The initial launch of Space Tug in November, 1982, requires the beginning of the Space Tug peculiar efforts in February, 1982, assuming that all of the common development has been completed in order to support the IUS program. Critical paths are identified by sequences of O's without slack time between separate tasks. The next paragraph will explain the terminology of the chart and the meaning of the symbols on the chart.

Four symbols are used to form the bars of the bar chart. Symbol *O* is used to designate those functions which are in the critical path. For example, the first critical path is derived for the IUS and consists of the following functions: contract software development, plan ground software development, EDD-executive/tracking/planning, program ground track/plan/executive software, verify executive/track/planning software, IUS mission planning and optimization, IUS abort planning, IUS planning mission specific EDD, IUS mission specific program, IUS mission program verification, IUS mission simulation training, conduct IUS mission operations, and IUS post-mission reports. None of these events can exceed its allocated time without slipping the program launch date. The symbol *E* is used to designate the span of time beginning at the earliest time all constraints are met for a particular activity to begin. The symbol *L* is utilized to indicate the span of time from the latest possible time an activity can begin through its completion. Each symbol designates one week of activity. If an activity is not in the most critical path it will contain the symbol *E* and the symbol *L* and either the symbol *O* or +. In that context, the symbol *O* indicates the overlap between bars representing an early start and a late start. For example, the task "analyze tug component characteristics" requires seven weeks to accomplish. The earliest it can begin is February 1983. There are six consecutive *E* symbols followed by a single *O* symbol followed by six consecutive *L* symbols. The *O* symbol is to be interpreted as being shared between the *E* and *L* activity periods. The + sign indicates program "slack", that is, the activity is not critical and may be accomplished at any time between the first *E* and last *L*.

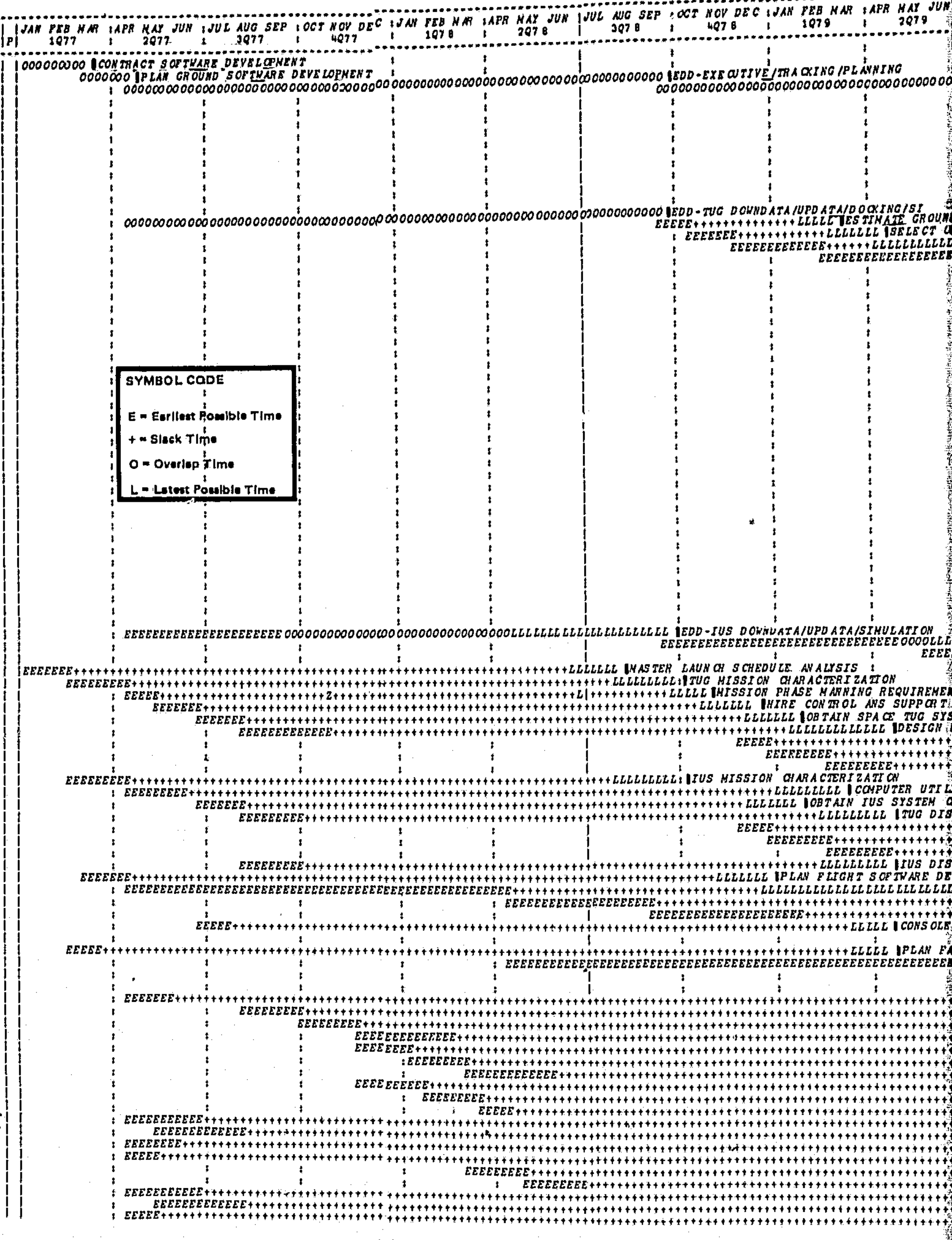

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Figure B-3. IUS/Tug Systems Development Schedule

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 NOV DEC : JAN FEB MAR : APR MAY JUN : JUL AUG SEP : OCT NOV DEC : JAN FEB MAR : APR MAY JUN : JUL AUG SEP : OCT NOV DEC
 4Q77    :   1Q78      :   2Q78      :   3Q78      :   4Q78      :   1Q79      :   2Q79      :   3Q79      :   4Q79

LOPMENT
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                                       000000000000000000000000000000000000000000000000000000 |PROGRAM GROU
                                                                                        00000000000000

0000000000000000000000000000000000000000000000000 |EDD-TUG DOWNDATA/UPDATA/DOCKING/SI
                                       EEEEE++++++++++++++LLLLL |ESTIMATE GROUND SOFTWARE SIZE
                                         EEEEEEE++++++++++++LLLLLLL |SELECT OPERATIONAL DATA SYSTEM
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                                                                                  EEEEEEEEEEEEEEEEEE

                                                                                  EEEEEEEEEEEEEEEEEE
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++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++LLLLLLL |OBTAIN SPACE TUG SYSTEM CHARACTERI
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++LLLLLLLLLLLL |DESIGN NETWORK INTERFACE SYSTEM
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                                                    EEEEEEEEE++++++++++++++++++++++++++++++++++++++++++
                                                           EEEEEEEEE+++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++LLLLLLLLL |IUS MISSION CHARACTERIZATION
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++LLLLLLLL |COMPUTER UTILIZATION PLAN
+++++++++++++++++++++++++++++++++++++++++++++++++++++++LLLLLLL |OBTAIN IUS SYSTEM CHARACTERISTICS
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++LLLLLLLLL |TUG DISPLAY FORMAT DESIGN
                                                EEEEE++++++++++++++++++++++++++++++++++++++++++++++++
                                                    EEEEEEEEE++++++++++++++++++++++++++++++++++++++++++
                                                           EEEEEEEEE+++++++++++++++++++++++++++++++++++++
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++LLLLLLLLL |IUS DISPLAY FORMAT DESIGN
++++++++++++++++++++++++++++++++++++++++++++++++++++++LLLLLLL |PLAN FLIGHT SOFTWARE DEVELOPMENT
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Schedule

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|   1Q80     |   2Q80     |   3Q80     |   4Q80     |   1Q81     |   2Q81     |   3Q81     |   4Q81     |   1Q82     |   2Q82

ND TX/PLAN/EX SOFTWARE
000000000000000000000 |VERIFY EXECUTIVE/TX/PLAN SOFTWARE
          0000000 |IUS MISSION PLANNING AND OPTIMIZAT
               000000000000 |IUS ABORT PLANNING
                    00000 |IUS MISSION SPEC EDD
                      000000000 |IUS MISSION SPEC PROGRAM
                            000000000 |IUS MISSION PROGRAM VERIFICATION
                                0000000 |IUS MISSION SIMULATION TRAINING
                                     OO |CONDUCT IUS MISSION OPERATIONS
                                  000000000 |IUS POST MISSION REPORTS

YSICAL PLAN
L |CONSTRUCT PHYSICAL PLANT
OOLLLLLLLLLLLLLLLLLLL |INSTALL OPERATIONAL DATA SYSTEM
          EE0000000000000000LL |DEVELOP IUS PROCEDURES AND RULES
                   EEEEEEEEEOOOOOLLLLLLL |PROGRAM IUS MISSION SIMULATION
                                                                  000000000000000000

                                                                                |AN

                  EEEEEEEEE+LLLLLLLLL |PREPARE IUS INTERAGENCY DOCUMENTS
                           EEEEEEEEE+LLLLLLLLL |IUS INTERAGENCY COORDINATION
          |TUG NETWORK DATA HANDLING REQUIREM EEEEE+++++++++++++++++++++++++++++++++++++++++++
            |TUG NETWORK DATA VALID PROCEDURES EEEEEEEEE+++++++++++++++++++++++++++++++++++++
                        |TUG NETWORK VALID TESTS  EEEEEEEEE++++++++++++++++++++++++++++++++++

OOLLLLLLLLLLLLLLLLLLL |INSTALL OPERATIONAL CONSOLES/HARDW

L |PROGRAM IUS DNDATA/UPDATA/SIMULATI
LLLLLLLLLLLLLLLLLLLL |VERIFY IUS DNDATA/UPDATA/SIM PROGR

++++++++++++++++++++++++++++++++++++++++LLLLL |DEFINE NETWORK TRACKING REQUIREMEN
++++++++++++++++++++++++++++++++++++++++++++LLLLLLLLL |NETWORK TRACKING VALID PROCEDURES
++++++++++++++++++++++++++++++++++++++++++++++++++LLLLLLLLL |NETWORK TRACKING VALID TESTS

++++++++++++++++++++++++++++++++++++++++LLLLL |IUS NETWORK DATA HANDLING REQUIREM
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++++++++++++++++++++++++++++++++++++++++++++++++++LLLLLLLLL |IUS NETWORK DATA VALID TESTS

|EDD-IUS FLIGHT PROGRAM
LLLLLLLLLLLLLLLLLLLL |PROGRAM IUS FLIGHT SOFTWARE
++++++++++++++++++LLLLLLLLLLLLLLLLLLLLLLL |IUS FLT PROGRAM VERIFICATION
EEEEEEEEEEEEEEEEEEEEE+++++++++++++++++++++++++++++++++++LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL |PROGRAM TUG DND
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EEEEEEEEEEEEEEEEEE+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++LLLLLLLLLLLL
           EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
L |MAINTENANCE SCHEDULE
+++++++LLLLLLLLL |DETERMINE IUS FAILURE MODES
+++++++++++++++LLLLLLLLL |IUS MISSION FAILURE EFFECTS
++++++++++++++++++++++LLLLLLLLLLLL |DESIGN IUS MISSION SIMULATION
++++++++++++++++++++++++++LLLLLLL |ANALYZE IUS COMPONENT CHARACTERIST
++++++++++++++++++++++++++++LLLLLLLLL |PREPARE IUS SYSTEMS HANDBOOK
++++++++++++++++++++++++++++++++++LLLLLLLLLLLL |PUBLISH/UPDATE IUS HANDBOOK
++++++++++++++++++++++++++++++LLLLLLLLL |IUS TRAINING REQ/CRIT/SIMSKED
++++++++++++++++++++++++++++++++++LLLLLLLLL |DEVELOP IUS TRAINING MATERIAL
++++++++++++++++++++++++++++++++++++++++LLLLL |IUS CLASSROOM TRAINING
+++++++++LLLLLLLLLLL |COMMON GND SW VALID TEST REQUIREMENE
++++++++++++LLLLLLLLLLLL |CONSOLE POSITION GUIDELINES
++++++++++++LLLLLLLL |IUS GND SW VALID TEST REQUIREMENTS
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JAN FEB MAR : APR MAY JUN : JUL AUG SEP : OCT NOV DEC : JAN FEB MAR : APR MAY JUN : JUL AUG SEP : OCT NOV DEC ||
    1Q82    :     2Q82    :     3Q82    :     4Q82    :     1Q83    :     2Q83    :     3Q83    :     4Q83    ||DESCRIPTION|

                                                                                                  ||CONTRACT SOFTWARE DEVELOPMENT
                                                                                                  ||PLAN GROUND SOFTWARE DEVELOPMENT
                                                                                                  ||EDD-EXECUTIVE/TRACKING/PLANNING
                                                                                                  ||PROGRAM GROUND TK/PLAN/EX SOFTWARE
                                                                                                  ||VERIFY EXECUTIVE/TK/PLAN SOFTWARE
                                                                                                  ||IUS MISSION PLANNING AND OPTIMIZAT
                                                                                                  ||IUS ABORT PLANNING
                                                                                                  ||IUS MISSION SPEC EDD
                                                                                                  ||IUS MISSION SPEC PROGRAM
                                                                                                  ||IUS MISSION PROGRAM VERIFICATION
                                                                                                  ||IUS MISSION SIMULATION TRAINING
                                                                                                  ||CONDUCT IUS MISSION OPERATIONS
                                                                                                  ||IUS POST MISSION REPORTS
                                                                                                  ||EDD-TUG DOWNDATA/UPDATA/DOCKING/SI
                                                                                                  ||ESTIMATE GROUND SOFTWARE SIZE
                                                                                                  ||SELECT OPERATIONAL DATA SYSTEM
                                                                                                  ||SIZE FACILITY/DESIGN PHYSICAL PLA
                                                                                                  ||CONSTRUCT PHYSICAL PLANT
                                                                                                  ||INSTALL OPERATIONAL DATA SYSTEM
                                                                                                  ||DEVELOP IUS PROCEDURES AND RULES
                                                                                                  ||PROGRAM IUS MISSION SIMULATION
00000000000000000000000000000000000 |VERIFY TUG DNDATA/UPDATA/DOCKING/S                           ||VERIFY TUG DNDATA/UPDATA/DOCKING/S
             0000000000000000 |DEVELOP TUG PROCEDURES AND RULES                                   ||DEVELOP TUG PROCEDURES AND RULES
                      000000000000 |DESIGN TUG MISSION SIMULATION                                 ||DESIGN TUG MISSION SIMULATION
                                     00000 |TUG MISSION SPEC EDD                                  ||TUG MISSION SPEC EDD
                 |TUG MISSION SPECIFIC PROGRAM 000000000                                          ||TUG MISSION SPECIFIC PROGRAM
                    |TUG MISSION PROGRAM VERIFICATION 000000000                                   ||TUG MISSION PROGRAM VERIFICATION
                         |TUG MISSION SIMULATION TRAINING 0000000                                 ||TUG MISSION SIMULATION TRAINING
                              |CONDUCT TUG MISSION OPERATIONS 00                                  ||CONDUCT TUG MISSION OPERATIONS
                                  |TUG POST MISSION REPORTS 00000000                              ||TUG POST MISSION REPORTS
      |ANALYZE TUG COMPONENT CHARACTERIST EEEEEEOLLLLLL                                           ||ANALYZE TUG COMPONENT CHARACTERIST
          |PREPARE TUG SYSTEMS HANDBOOK EEEEEEOOOLLLLLL                                           ||PREPARE TUG SYSTEMS HANDBOOK
            |PUBLISH/UPDATE TUG SYSTEMS HANDBOO EEEEEEOOOOOOOLLLLLL                               ||PUBLISH/UPDATE TUG SYSTEMS HANDBOO
              |PROGRAM TUG MISSION SIMULATION EEEEEEEEOOOOOLLLLLLLL                               ||PROGRAM TUG MISSION SIMULATION
               EEEEEEE+++LLLLLL|TUG MISSION PLANNING AND OPTIMIZAT                                ||TUG MISSION PLANNING AND OPTIMIZAT
                  EEEEEEEEEEEOOOLLLLLLLLL|TUG ABORT PLANNING                                      ||TUG ABORT PLANNING
            |PREPARE TUG INTERAGENCY DOCUMENTS EEEEEEEE+LLLLLLLL                                  ||PREPARE TUG INTERAGENCY DOCUMENTS
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         |TUG TRAINING REQ/CRIT/SIMSKED EEEEEEEE+++LLLLLLLL                                       ||TUG TRAINING REQ/CRIT/SIMSKED
            |DEVELOP TUG TRAINING MATERIAL EEEEEEEE+++LLLLLLLL                                    ||DEVELOP TUG TRAINING MATERIAL
                   |TUG CLASSROOM TRAINING EEEEE+++++++LLLLL                                      ||TUG CLASSROOM TRAINING
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                                                                                                  ||PROGRAM IUS DNDATA/UPDATA/SIMULATI
                                                                                                  ||VERIFY IUS DNDATA/UPDATA/SIM PROGR
                                                                                                  ||MASTER LAUNCH SCHEDULE ANALYSIS
                                                                                                  ||TUG MISSION CHARACTERIZATION
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                                                                                                  ||HIRE CONTROL ANS SUPPORT STAFF
                                                                                                  ||OBTAIN SPACE TUG SYSTEM CHARACTERI
                                                                                                  ||DESIGN NETWORK INTERFACE SYSTEM
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                                                                                                  ||OBTAIN IUS SYSTEM CHARACTERISTICS
                                                                                                  ||TUG DISPLAY FORMAT DESIGN
                                                                                                  ||IUS NETWORK DATA HANDLING REQUIREM
                                                                                                  ||IUS NETWORK DATA VALID PROCEDURES
                                                                                                  ||IUS NETWORK DATA VALID TESTS
                                                                                                  ||IUS DISPLAY FORMAT DESIGN
                                                                                                  ||PLAN FLIGHT SOFTWARE DEVELOPMENT
                                                                                                  ||EDD-IUS FLIGHT PROGRAM
                                                                                                  ||PROGRAM IUS FLIGHT SOFTWARE
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LLLLLLLL |PROGRAM TUG DNDATA/UPDATA/DOCKING/                                                      ||CONSOLE ORGANIZATION
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LLLLLLLLLLLLL |EDD-TUG FLIGHT PROGRAM                                                             ||PLAN FACILITY UTILIZATION
+++++++++++LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL |PROGRAM TUG FLIGHT SOFTWARE                          ||EDD-TUG FLIGHT PROGRAM
++++++++++++++++++++++++++++++++++++LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL |TUG FLT PROGRAM VERIFICATION ||PROGRAM TUG FLIGHT SOFTWARE
                                                                                                  ||TUG FLT PROGRAM VERIFICATION
                                                                                                  ||MAINTENANCE SCHEDULE
                                                                                                  ||DETERMINE IUS FAILURE MODES
                                                                                                  ||IUS MISSION FAILURE EFFECTS
                                                                                                  ||DESIGN IUS MISSION SIMULATION
                                                                                                  ||ANALYZE IUS COMPONENT CHARACTERIST
                                                                                                  ||PREPARE IUS SYSTEMS HANDBOOK
                                                                                                  ||PUBLISH/UPDATE IUS HANDBOOK
                                                                                                  ||IUS TRAINING REQ/CRIT/SIMSKED
                                                                                                  ||DEVELOP IUS TRAINING MATERIAL
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                                                                                                  ||COMMON GND SW VALID TEST REQUIREME
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                                                                                                  ||IUS GND SW VALID TEST REQUIREMENTS
                                                                                                  ||DEFINE IUS OPERATOR CERT/CRITERIA
++++++++++++++++++++++++++++++++++++LLLLLLLLL |DETERMINE TUG FAILURE MODES                        ||DETERMINE TUG FAILURE MODES
++++++++++++++++++++++++++++++++++++++++++++LLLLLLLL|TUG MISSION FAILURE EFFECTS                  ||TUG MISSION FAILURE EFFECTS
+++++++++++++++++++++++++++++LLLLLLLLLLL|TUG GND SW VALID TEST REQUIREMENTS                       ||TUG GND SW VALID TEST REQUIREMENTS
+++++++++++++++++++++++++++++++++++++LLLLLLLLLLLL|TUG CONSOLE POSITION GUIDELINES                 ||TUG CONSOLE POSITION GUIDELINES
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4.0 MILESTONES

4.1 IUS/TUG SYSTEMS DEVELOPMENT PROCESS MAJOR MILESTONES

Figure B-4 is a condensed version of the IUS/Tug Systems Development Schedule Figure B-3. Shown on this chart are fourteen composite functions which indicate the major milestones in the IUS/Tug development process. It should be noted that the Tug ground software development effort has been split into three distinct phases with the Tug software requirements definition parallel in time with the IUS software development task.

In order to properly size the ground computer it is necessary to have reasonably accurate memory and execution speed estimates for common IUS and Tug ground software and exclusive IUS and Tug ground software. This is why the equation defining phase of the Tug ground software is scheduled for the second quarter of 1977 and terminates in the third quarter of 1978.

The major milestone start and completion dates appearing on this chart were derived from the constraints of the critical path which collectively compromise thirty individual tasks which must be completed on schedule and in sequcnce in order to meet the IUS and Tug operations schedule.

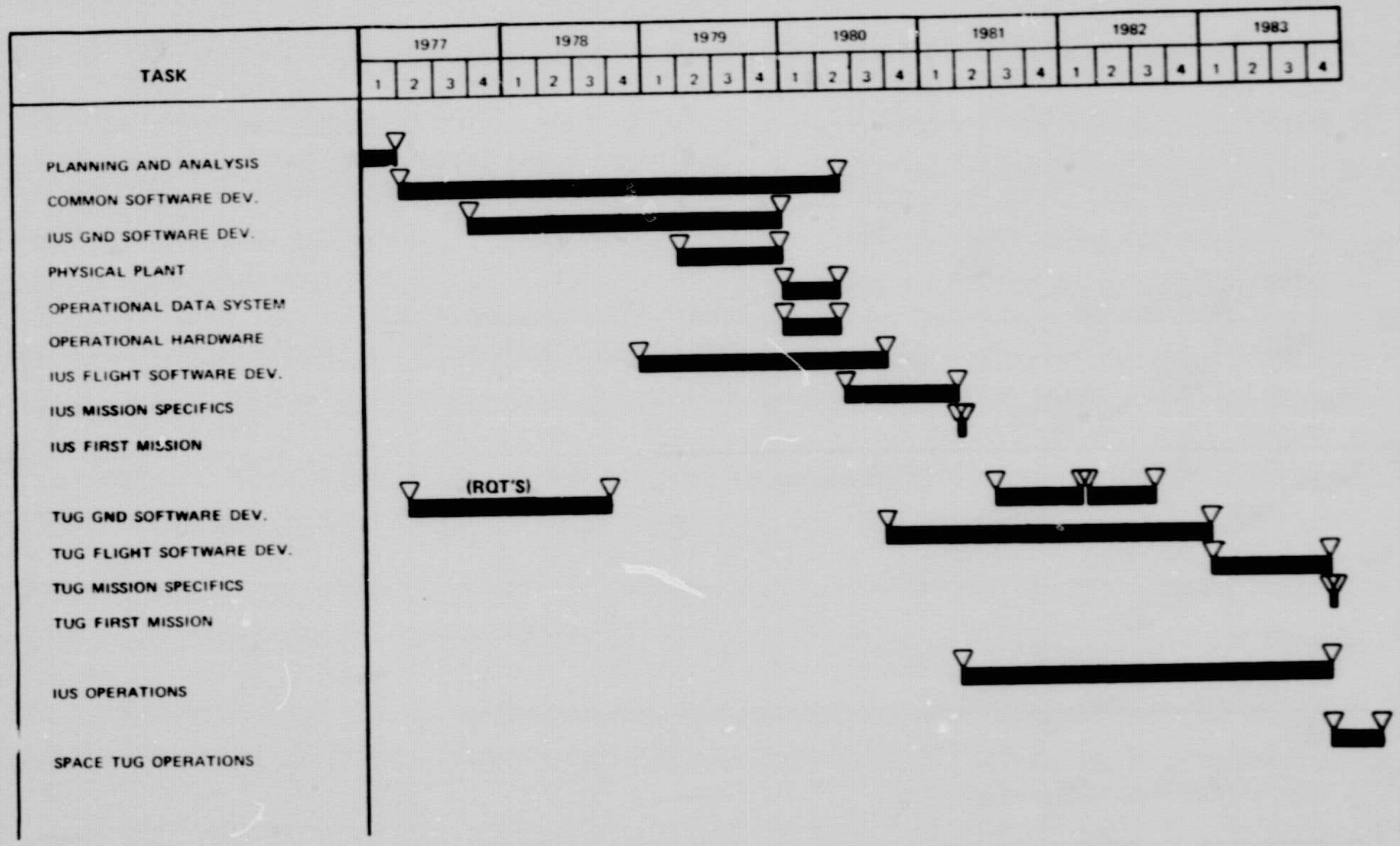


Figure B-4. IUS/Tug Systems Development Process Major Milestones

PART C

SUPPORT RESEARCH AND TECHNOLOGY (SR&T)

1.0 POTENTIAL NEW SR&T PROGRAMS

The information generated during this study has identified several areas of technology which should receive further investigation. These potential activities are described in this part of the final report in accordance with the documentation requirement specified by DR MA-03 of the contract.

1.1 RENDEZVOUS TARGETING ONBOARD SOFTWARE

1.1.1 Status

The feasibility of automatically targeting a rendezvous sequence based on inflight navigation and externally derived target information has been theoretically determined. The limiting factor in prior investigations has been the available CPU speed of airborne digital computers. The current state of the art in airborne digital computer design indicates that CPU speeds approaching 500,000 equivalent adds per second will be available in the Space Tug time frame. Previous studies have estimated the requirements for rendezvous targeting to be on the order of 480,000 equivalent adds per second. It is, therefore, technically feasible to consider an onboard rendezvous targeting capability for Space Tug.

1.1.2 Justification

The Mercury, Gemini, Apollo and Skylab programs relied upon ground based computation for rendezvous targeting. The ground based computations were uplinked to the onboard systems and implemented in flight. This required extensive ground based facilities, and personnel for implementation. It is likely, the cost of the associated ground operations out weigh the cost of implementing the software onboard. In the general case, the cost of implementing software onboard is less than the equivalent implementation on the ground, although the cost per word for onboard software may be higher. Requirements of support personnel and input/output servicing dominate the ground implementation of rendezvous targeting. Program cost may be lessened by moving the implementation of rendezvous targeting to the onboard system, if the computer technology can support the required CPU speed. It appears that the CPU speed necessary will be available by the time Space Tug design is finalized.

1.1.3 Technical Plans

Rendezvous targeting onboard equations have been demonstrated theoretically. What is needed is the development of new schemes to minimize onboard computation time and to optimize the rendezvous targeting algorithms. In the proposed effort, a period of analysis precedes the decision for rendezvous targeting in a flight-type computer. Algorithms will be designed, optimized, and coded. The resulting software will be evaluated in both hardware and software simulators.

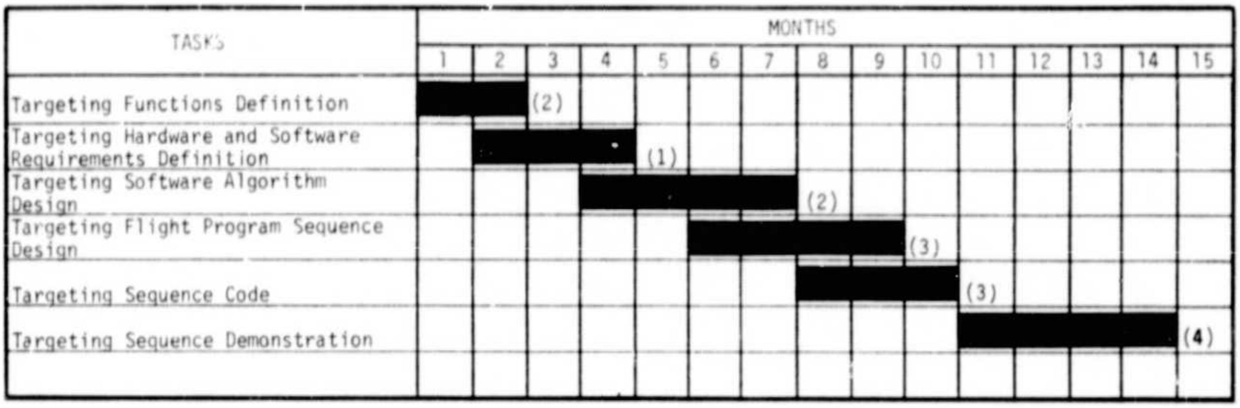
1.1.4 Resource Requirements

The total direct labor estimated for this effort is 4.3 man years. Skills required in this effort will be orbital mechanics, advanced airborne avionics hardware/software development and software verification. Verification would best be accomplished on Tug simulation equipment.

1.1.5 Target Schedule

The task flow schedule shown in Table C-1 indicates the major areas of effort and sequence of occurence. The duration of the task is 14 months and should be completed in a time frame consistent with early airborne and ground software development decisions.

Table C-1. Rendezvous Targeting Onboard Software Development



1.2 AUTOMATIC DOCKING FEASIBILITY DEMONSTRATION

1.2.1 Status

All docking operations undertaken by the United States Space Programs have been manually guided connections between a stabilized target vehicle and the manually controlled pursuing vehicle. Schemes based upon slow scan television interrogation of the target and man-in-the-loop (ground) control of docking are expensive in docking support software required and technically marginal in the time delays involved in supporting transfer of information from the physical condition in orbit to the ground controller. Past docking efforts have involved a terminal rendezvous phase which terminates with the pursuing and target vehicles and a stationary relationship prior to the actual docking, which was then flown manually. Parametric analysis of the docking problem performed during the period of this study indicates that an uninterrupted transfer from rendezvous terminal phase through docking is feasible. Prior studies have shown that two problems dominate the automatic docking consideration: airborne computer timing and docking sensor range.

1.2.2 Justification

One of the primary features of the Space Tug program is the ability to dock with expensive satellites and return them to earth or service the satellites

on orbit. Since the Space Tug is an unmanned vehicle, and man-in-the-loop ground based docking control at extended distances is marginal, an automated docking technique is a reasonable consideration. Previous studies have shown that the limiting factor in automated docking is the computer speed required to maintain relative navigation with a target while at the same time performing guidance, control, sequencing and telemetry functions. The state of the art in computer development indicates that machines having a CPU capability approaching 500,000 equivalent adds per second will be available in the Space Tug time frame. It is, therefore, feasible to consider transfer of docking authority to the onboard system.

1.2.3 Technical Plan

The algorithms to accomplish docking will be optimized from existing equation definitions, then coded and implemented in a flight computer. The problem of rendezvous and docking requires a mechanical simulation of the target and a mechanical simulation of the pursuit vehicle. Each of the simulators must provide six degrees of freedom for each element of the rendezvous problem. The software developed to support docking will be implemented in a flight-type computer, which will control the motion of the pursuit vehicle of the mechanical simulator. A second computer source will drive the target vehicle in the motions which may be encountered during docking. The long range mechanical simulator may be to scale. It must be augmented with a short range full size docking assembly in order to simulate the final closure and latch.

1.2.4 Resources Requirements

The total direct labor estimated for this effort is 3.8 man years. Skills required in this activity will be terminal docking and alignment equipment, software and the associated simulation of docking operations.

1.2.5 Target Schedule

The task flow schedule shown below in Table C-2 indicates the major areas of effort and the sequence and duration of each. The duration of the total task is 14 months and should be completed in a time frame consistent with major ground and airborne system planning. This task utilizes a docking simulator but does not include estimates for the development of simulator facilities.

Table C-2. Automatic Docking Feasibility Demonstration

TASKS	MONTHS														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Define Docking Functions	■	■	(2)												
Define Docking Hardware and Software Requirements		■	■	■	(1)										
Define Docking Software Algorithms				■	■	■	■	(3)							
Design Flight Program Docking Sequence							■	■	(1)						
Code Docking Sequence									■	■	■	(3)			
Demonstrate Docking Sequence											■	■	■	■	(3)

1.3 LEVEL I AUTONOMY FLIGHT SOFTWARE DEVELOPMENT

1.3.1 Status

Until recently, completely autonomous space missions were not feasible on the basis of qualified avionics computer CPU speeds and navigation uncertainties derived from hardware error and uncertainties. Recent programs sponsored by the Department of Defense have shown autonomous navigation is possible based upon ILT and star tracker hardware implementations coupled with a high speed onboard computer. The EXO-atmospheric Space Vehicle Software Study conducted in 1973 by IBM investigated the problems involved in implementing Level I autonomy. The conclusions reached were that an onboard computer with memory capacity of approximately 36,000 32-bit words and computational capability of approximately 485,000 equivalent adds per second will be required to implement the Level I autonomy flight software. At that time no such machine existed. Today this memory size is attainable with existing hardware and the CPU speed should be a reality within the next two or three years.

1.3.2 Justification

Anything less than a fully autonomous Tug vehicle will require real time ground support which can be translated into facility and personnel costs. The possibility of eliminating or reducing this expense versus the additional cost for onboard capability is a reality that should be pursued.

1.3.3 Technical Plan

Existing autonomous software schemes such as MASCOT and OPGUIDE have been developed and coded in PLI and Fortran languages for demonstration purposes on high speed, ground based digital computers. The technical approach suggested is to begin with the existing software coding and modify that coding for implementation in an airborne digital computer having the computational speed and memory size requirements necessary to implement the autonomous flight software. The resulting coded program will be tested in simulated flight conditions in the flight computer, with the test being monitored by a large, high-speed ground computer, which will simulate the external inputs to the onboard computer. A further test program involving the utilization of autonomous flight software in a passenger mode or in a switch-in/switch-out mode during actual flight testing is recommended.

1.3.4 Resources Requirements

The total direct man years estimated for this effort are 4.6 man years. Skills required for this effort cover every aspect of autonomous space flight and Space Shuttle payload interface.

1.3.5 Target Schedule

The task flow schedule shown in Table C-3 illustrates the major areas of effort and the sequence and duration of each. The duration of the total task is 13 months. The purpose of this effort is not to deliver a flight program for Space Tug but to prove Level I concept feasibility.

Table C-3. Level I Autonomy Flight Software Development

TASKS	MONTHS														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Define Level I Functions				(2)											
Define Level I Hardware and Software Requirements						(2)									
Define Level I Algorithms										(4)					
Define Flight Program Sequence										(2)					
Implement Demo Software												(3)			
Demonstrate Level I Program														(4)	
*Flight Test in Passenger Mode		(Undefined)													
*Task has not been Included in Manpower or Schedule Estimates															

1.4 MINIMIZATION OF FLIGHT CONTROL (PERSONNEL) INTERACTION

1.4.1 Status

The Mercury, Gemini, Apollo and Skylab programs relied heavily upon ground intervention and augmentation of inflight decisions. In many cases, these decisions were analyzed in the pre-mission phase and were implemented by ground based personnel following a "mission rules" document. It follows that a decision which can be analyzed in advance may also be programmed into a ground based digital computer. In previous work ("A Model for the Evaluation of Information Management Systems for Long Duration for Space Station Mission"), the problem of decision authority was addressed. The dominant factor was demonstrated to be the time required for interpretation of contingency situations and the formulation and execution of an appropriate response. The "decision loops" included a loop closed through an onboard computer, a loop closed through a ground based computer and a loop closed through a human, interacting with a ground based computer. The conclusions were that all three modes of decision authority are required. The human interaction, however, was limited to those functions which the human can provide more accurately than the computer. Those functions were primarily in the area of pattern recognition. Therefore, a decision which can be reduced to the level of a mission rules criteria check can be programmed for implementation either onboard or on the ground.

1.4.2 Justification

The majority of the expense in a Space Tug Control Center design is the result of ground based software development. This software is primarily to service displays and accept reactions by controllers and flight support personnel. In a long duration program, such as Space Tug, the cost of supporting the human element of the system will approximate 40 million dollars. A large portion of that expense can be avoided at the cost of increasing expenditures for developing the ground software closed loop implementation processes.

1.4.3 Technical Plan

As operational concepts are developed for the IUS and Space Tug programs, based upon the flight characteristics and avionics characteristics of the vehicle, operational tasks will be separated into decisions which must be implemented onboard, decisions which must be implemented on the ground, and decisions which must be implemented by human interaction.

The decisions falling into the first two categories will then be analyzed and software estimates generated for each operational tasks. The third class of decisions will be automated and the feasibility demonstrated using a ground computer system. Following the feasibility demonstration each function will be documented with development cost estimated.

1.4.4 Resources Requirements

The total direct labor estimated for this effort is 2.2 man years. Skills required for this effort include knowledge of airborne and ground operational functions and the capabilities of systems involved to handle the various decision processes.

1.4.5 Target Schedule

The task flow schedule shown in Table C-4 illustrates the major areas of effort and the sequence and duration of each. The duration of the total task is nine months. The purpose of this activity is not to provide detail mission rules and automated solutions but to prove concept feasibility.

Table C-4. Minimization of Flight Control (Personnel) Interaction

TASKS	MONTHS														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Define Onboard, Ground, and Ground Controller Decisions	■	■	(2)												
Define Decision Criteria for Automation		■	■	(2)											
Define Decision Process for Automation				■	■	(3)									
Demonstrate Decision Process						■	■	■	■	(3)					

1.5 ORBITAL NAVIGATION

1.5.1 Status

Orbital navigation was performed in the Saturn/Apollo program by integrating the equations of motion and performing minor corrections due to gravity and atmospheric drag. Orbital navigation over an extended mission period resulted in an accumulation of state errors which, since the system was open loop, were not corrected, and propagated into the translunar burn phases. With the development of ILT technology and the coupling of ILT landmark navigation and stellar sensed attitude update information, it is now theoretically possible to navigate

in a closed loop system. To do this will require the development of a detailed gravity model, a detailed atmospheric model, and techniques for servicing the star tracker and ILT input information in a central computer onboard the vehicle.

1.5.2 Justification

A large amount of money has been spent in the past maintaining a ground based radar tracking network which provides state vector information to a central computer which then in turn calculates the trajectory of the orbiting body. The expense of implementing that technique is strictly overhead to the decision process. Any decision based upon navigation parameters will ideally take place at the point at which the navigation information is derived. That point can be, under existing technology, at the orbiting vehicle.

1.5.3 Technical Plan

Begin development of a detailed gravity model based upon empirical satellite observations. Develop a detailed atmospheric model based upon empirically derived drag coefficients. Adapt the ILT servicing software and the star trackers servicing software from DoD implementations to NASA Space Tug implementation. Combine all inputs into a high speed airborne digital computer having 500,000 equivalent adds per second (or higher speed) and demonstrate the resulting software package in simulation. Following a demonstration in the simulation mode, the system could be flown in a passenger mode for inflight test demonstration.

1.5.4 Resources Requirements

The total direct labor estimated for this task is 4.3 years. Skills required for this effort are orbital navigation, airborne flight software, ILT and star tracker operation.

1.5.5 Target Schedule

The task flow schedule shown in Table C-5 illustrates the major areas of effort and the sequence and duration of each. The duration of the total task is 10 months. The purpose of this effort is to demonstrate the feasibility of a closed loop orbital navigation system for Tug.

Table C-5. Orbital Navigation

TASKS	MONTHS														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Define Tug Gravity Model			(2)												
Define Tug Drag Coefficients			(2)												
Adapt DoD ILT Service Software					(3)										
Adapt DoD Star Tracker Software					(3)										
Develop Closed Loop Orbital Navigation Software Routine							(3)								
Demonstrate Closed Loop Orbital Navigation Software											(4)				
*Flight Test in Passenger Mode			(Undefined)												
*Task has not been Included in Manpower or Schedule Estimates															